ABSTRACTS OF ATM-2021

75th Annual Technical Meeting of Indian Institute of Metals

Date: 14th – 15th November 2021

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ABSTRACTS OF ATM-2021

Preface

The Indian Institute of Metals in association with Tata Steel is virtually organizing 75th Annual Technical Meeting (ATM) during 14th to 15th November 2021.

The ATM presentations are scheduled on 14th and 15th of November 2021 on a virtual platform. The scope of ATM encompasses modelling, mineral extraction and beneficiation, manufacturing of ferrous, non-ferrous and other materials, development and characterization of products, environment and other sustainability issues, corrosion, tribology, surface engineering, joining technologies, casting, powder metallurgy, non-destructive testing, emerging technologies, industry automation etc.

This year eight parallel technical sessions and a common E-poster session is being conducted which broadly includes the following themes:

- Raw Materials
- Process Metallurgy
- Products
- Non-ferrous Metals
- Energy, Environment and Waste Utilization
- Advances in Materials Science and Technology
- Industry 4.0
- Safety

There has been an overwhelming response to the call of papers for ATM 2021. More than 800 technical abstracts were received from various organizations. All of them were reviewed and categorized in the above themes and finally collated in the form of an abstract compilation.

We are thankful to all the authors for their valuable contribution without which this volume might not have taken the present shape. We are also indebted to all the sponsors of this event for their generous funding.

Finally, we wish all the participants an informative and interactive experience at ATM 2021.

ATM-2021

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THEMES

I. RAW MATERIALS

II. PROCESS METALLURGY

III. PRODUCTS

IV. NON-FERROUS METALS

V. ENERGY, ENVIROMNMENT & WASTE UTILIZATION

VI. ADVANCES IN MATERIALS SCIENCE & TECHNOLOGY

VII. INDUSTRY 4.0

VIII. SAFETY

ANNUAL TECHNICAL MEETING 2021- SCHEDULE FOR ORAL SESSIONS

14th NOVEMBER 2021

Time/ Hall	Hall 1	Hall 2	Hall 3	Hall 4	Hall 5	Hall 6	Hall 7	Hall 8
14:00 - 16:15 hrs	Raw Materials	Industry 4.0	Products	Non-Ferrous Metals	Energy	Advances in Materials Science	Process Metallurgy	Safety
16:15 - 19:30 hrs	Raw Materials	Industry 4.0	Products	Non-Ferrous Metals	Energy	Advances in Materials Science	Process Metallurgy	Safety

15th NOVEMBER 2021

Time/ Hall	Hall 1	Hall 2	Hall 3	Hall 4	Hall 5	Hall 6	Hall 7	Hall 8
08:30 - 10:45 hrs	Raw Materials	Industry 4.0	Products	Non-Ferrous Metals	Energy	Advances in Materials Science	Process Metallurgy	Safety
10:45 - 13:00 hrs	Process Metallurgy	Industry 4.0	Products	Non-Ferrous Metals	Energy	Advances in Materials Science	Process Metallurgy	Safety
13:00 – 13:30 hrs	LUNCH BREAK							
13:30 - 15:45 hrs	Process Metallurgy	Advances in Materials Science	Process Metallurgy	Advances in Materials Science	Energy	Advances in Materials Science	Process Metallurgy	Safety
15:45 - 18:00 hrs	Process Metallurgy	Advances in Materials Science		Advances in Materials Science	Advances in Materials Science	Advances in Materials Science	Process Metallurgy	Advances in Materials Science

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Raw Materials

KEYNOTE LECTURES

Technological Advances in Meeting the Challenges of Provisioning Metals for Sustaining Societal Development

Khanindra Pathak
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To meet the developmental demands and societal requirements, the demands of metal is ever increasing. However, the demand patterns have changed recently and those of non-conventional minerals and metals are also increasing. Substitute of metals have impacted the supply chains. Recycling is facing different challenges. Mining of low-grade deposits and reclaims of tailings maintaining safety standards and protecting the environment have induced new techno-economic challenges. For the higher productivity and safety in various activities in metals' provisioning under complex domains of constraints, technological advances are called for.

Data driven management, prognostic maintenance, remote and automated operations using AI and IOT have opened new possibilities in the mining and metallurgical industry. Converting waste to wealth through advanced technology for enhancing quality of life is being researched and demonstrated increasingly. At the same time there is also a growing interest in applying our traditional knowledge and local solutions for some of the environmental and safety related problems. Evolving simpler solutions with affordable means should also be considered as advanced approaches for meeting the challenges. A culture of demonstrative innovation and adoption of advanced technology for progressive transformation in the mineral industry will need a new academic curriculum, new skill development approaches and smart and data driven management.

This lecture discusses some global examples and attempts to emphasis on developing a national level road map for sustainable and responsible mining. To this end recommendation will cover, inter alia, the required academic research and educational program for establishing tools and indicators to enhance performances and to ensure that key mining and environmental risks are managed responsibly.

Advanced Modelling and Simulation of Comminution using the Discrete Element Method

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Recent advances in particle breakage modelling, besides microscale population balance models (PBM) and the discrete element method (DEM) now make possible the simulation of crushing and grinding operations using commercial software. Depending on the type of comminution machine simulated either embedded breakage is described, or an option is made to describe breakage using the specially formulated PBM. In the heart of both resides the Tavares breakage model, which is a suite of mathematical equations that describe the different modes of fragmentation (body or surface), besides breakage probability, energy-dependent fragment distribution and weakening due to unsuccessful stressing events. The work presents examples of application of the approach to simulate ball and stirred mills, besides selected crushers, analysing their throughput, power and product size distribution.

Process Intensification in the Separation of Fine Minerals

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The transition from a carbon to a metals-based economy is creating an unprecedented demand for minerals, and in turn a diabolical process engineering challenge, given the decreasing grade of the accessible ore, the need to address new and more complex mineralogy, while reducing the environmental footprint.
This challenge demands transformational change to the practice of minerals processing, including the need for process intensification. This presentation examines recent developments associated with the Reflux Classifier to illustrate how it is possible to achieve significant improvement in separation efficiency, with a significant increase in processing ‘‘speed”. Here, it is necessary to control the forces that act on the particles in new ways to enhance the selectivity and ultimately the segregation of the valuable particles from the gangue. The presentation covers both gravity separation and flotation, exploring the application of forces that exploit differences in particle density and differences in surface properties within a hydrodynamic medium such as water.

Bulk Solids in Iron and Steel Making Industry: Storage, Flow and Handling

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Bulk materials handling operations perform a crucial function in the iron and steel making industry. It is important that the storage and handling systems be designed and operated to achieve maximum efficiency and reliability. The purpose of this presentation is to highlight the present state of knowledge associated with bulk handling testing and analytical and numerical methods to overcome challenges, e.g. spillage, blockage, and wear. Over the past several decades, much progress has been made in the theory and practice of reliable flow properties test procedures and analytical methods. These aid in the design of bulk solids storage and discharge equipment and optimisation to allow for increased efficiency, throughput and service life. With the advancement of simulation techniques and computer power, Discrete Element Method (DEM) has been widely used across various applications to simulate increasingly complex processes and geometries. The application of large-scale DEM modelling has become significantly beneficial in solving iron and steel making industry problems to improve bulk materials handling equipment design and operation. DEM parameters calibration approaches and examples of collaborative validation efforts will also be described. A series of case studies of industrial applications will be presented, including analysis of transfer chute material hang-up and rhino horning, wear, and bin and hopper flow.

Step One of Improving Tailings

Mike Cook
Director of MINEXXT, Inc. Golden, Colorado, USA

The majority of tailings' applications utilize thickeners for the final stages of mineral processing; however, operations often fail to recognize that this is also the first critical step in the tailings' disposal process. Operations are continuously under pressure to increase tonnages, improve efficiencies and to reduce operating costs. Incremental increases or changes in feed characteristics, usually result in an increase of solids and hydraulic loading on the thickeners. In most cases, it is to a point where the thickeners fail to meet the targets required for optimal deposition or, for efficient filtration in say a paste or backfill application.
Thickeners are often neglected, yet they are the simplest and least expensive piece of equipment to upgrade. Typical improvements for tailing applications are increasing the underflow densities, improving overflow clarities, reducing flocculant consumption, increasing the volume of

recovered water, better control, and more consistent performance. Simple and well proven steps are available to achieve all these improvements and the cost is surprisingly low, especially considering the short payback period or when comparing it with the cost of a new thickener.
This paper highlights the key components within a thickener that can be upgraded, and the latest technologies that provide the greatest impact on the performance or accommodate changes in thickener duties. Some examples and results of successful upgrades are provided, along with a description of what to upgrade, how to upgrade, and what the key benefits of upgrading actually are.

New Horizons for CO_2 Utilization

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Carbon dioxide is a waste gas in nearly all industrial processes worldwide. The generation of CO_2 on such a large scale has alarming consequences for the world. The capture of CO_2 has been accomplished using amines, sodium hydroxide, or sodium carbonate scrubbing operations. The question that comes next is, what do we do with all the CO_2? Much research has gone into finding ways to either sequester CO_2 in the ocean or underground, but these methods only contain a stockpile of CO_2 and are costly rather than profitable. Research into the effective utilization of CO_2 is far more appealing to industry because it generates profits from the creation of useful products. Michigan Tech has studied the conversion of CO_2 into more useful materials via an electrochemical conversion. Products such as syn. gas, ethanol, and oxalic acid among others may be produced. Oxalic acid has an important application in mining for the extraction of rare earth elements from other waste materials like aluminium process waste (red mud). The future of carbon dioxide lies in the ability to produce valuable materials from a waste gas.

ORAL PRESENTATIONS

Implementation of Coal Quality Management System (CQMS) in Kathautia Opencast Coal Mine (KOCCM)

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KOCCM of M/s. Hindalco Industries Limited belongs to Daltanganj coalfield. Rajhara-B and Pandua Top are the two main mineable seams of KOCCM with an average GCV of ~5200 kCal/kg. The most salient feature of this coal is higher GCV with high total moisture (~25%) due to relatively higher surface moisture (~ 18%) of that coal. A coal quality management system (CQMS) has been developed (1) to optimise the coal production, (2) to reduce the landed cost, and (3) to increase the net heat value of coal during burning. Broadly CQMS is subdivided into (1) mining process management, (2) stockyard management, (3) loading & transportation management and (4) coal sampling & assessment of quality management. Within these, mining process management is the key process to control and improve coal quality. Blasting is done only within the coal seam to reduce contamination from roof and floor. Before drilling and blasting bench top properly cleaned and after blasting in coal, shale/stone are removed by selective mining if there is any inter-banded shale/dirt band. Dedicated cleaned dumpers are used to stock coal from pit to stockyard where the coal is stocked for approx. 14 days to reduce the surface moisture. Further the coal is transported to railway siding through dumpers. In all the cases proper care is taken to minimise dilution due to floor material in the stockyard/railway siding. Before loading in wagons, empty rakes are minutely checked to ensure that there are no stones/ shale etc. Based on IS 436, 1964 regular basis coal sampling are being done from mine face, stockyard and railway wagon. Self as well as 3rd party coal quality assessment is further being done based on IS 1350 (Part-I & II). Strong implementation of CQMS including formation of task force assist to achieve the specific coal quality and stable calorific value as targeted. Therefore, it not only has positive impact on strict quality control but also in operational economy.

Characterization of Suitable Backfill Material and Filling Technique for Pumped Slurry Blind Backfilling in Underground Coal Mines

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Sand is considered as the most optimum material for backfilling but in the recent times, a huge amount of sand depletion is taking place its excessive use in the construction industry. But, in the same time, the replenishment is not fulfilled leading to huge sand depletion. In order to overcome this perilous situation, the use of alternative materials for backfilling purpose is the dire need of the hour. This study assesses to find the optimum mix proportions of bottom ash and sand as a backfill material and technique of pumped slurry blind backfilling in underground mines. Different physical characterization tests such as granulometry, bulk density, specific gravity, EDX, proximate analysis, moisture content and porosity have been conducted on both bottom ash and sand individually, and also on the varying mix proportions of bed ash and sand. The different mix proportions of bottom ash and sand is prepared for this study, i.e. 30 % bottom ash to 70 % sand, 40 % bottom ash to 60 % sand, 50 % bottom ash to 50 % sand and 60 % bottom ash to 40 per cent sand. Pumped slurry blind backfilling has been conducted with prepared mix proportion of bottom ash and sand on the laboratory prototype of a mine model and the technique is based on inflow rate, direction of flow and maximum filled up area covered by slurry. From the study, the best and second best mixture has found to be 30 % bottom ash to 70 % sand and 40 % bottom ash to 60 % sand on the basis of suitable physical characteristics, smooth flowability, good solid packing up to the roof of the mine model, maximum covered volume and minimum compressibility.

Beneficiation studies of Banded Hematite Jasper ore of Joda region, Eastern India

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The present paper describes the beneficiation of the banded hematite jasper (BHJ) ore from Joda area, eastern India. The main purpose of this study is to produce a pellet grade concentrate from the BHJ ore. The feed sample contained total Fe (36.31%), SiO_2 (46.73%), Al_2O_3 (0.50%) and loss of ignition (1.05%). Size-wise chemical analysis indicated that the finer fraction contained more silica and less iron value. Liberation analysis indicated that maximum iron grains were liberated below 150-micron size. Beneficiation studies using various unit operations such as hydro-cyclone, falcon concentrator, Wet High Intensity Magnetic Separation (WHIMS) and flotation etc. were carried out to up-grade the iron values and to reduce the gangue content. The separation techniques were decided based on particle size and properties for effective separation. The Hydro-cyclone overflow portion contained only 26% Fe with 54% SiO_2 hence, it was rejected. The cyclone underflow was further subjected in falcon concentrator. It was observed from the data that about 40% of solids could be recovered in the falcon underflow, but the grade of concentrate (54.20% Fe) was not as high as required for pellet feed. The Falcon underflow portion was again treated in WHIMS. It was observed from the data that grade of iron could be increased upto 58.16% with a yield of 34.00%. The silica content of this concentrate was 12.83% and finally, Flotation test was carried out on the WHIMS concentrate. It was observed from the data that the grade of ore could be raised upto 62.90% with 9.2% of silica values at a yield of approximately 28.4%.

Improving Ball Mill Performance by Optimising the Sizing Cyclone for Reducing the Recirculation Loads

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Comminution is the major unit operation in any mineral processing plant, which consumes higher power and consumables. Pellet plants require fine ore particles in their feed (generally less than 150 µm with 70 to 80% pass through 40 µm) to maintain the required quality. Due to the

heterogeneity of raw material, there is variation with respect to the raw material chemical properties, hardness, texture, and comminution characteristics. The ball mill operating parameters like the feed rate, dilution ratio, ball charge, cyclone density, particle separation in cyclone dictates the recirculation load in mills. In the present investigation, the impact of the separation efficiency in sizing cyclone, has been studied with multiple factors. Ball mill and cyclone studies were carried out by varying the process variables such as the particle size, bonds work Index, cyclone feed density, spigot, mill discharge density, cyclone pressure and mill current were analysed in the ball mill and cyclone. The effect of each variable on the responses on recirculation load and particle size in cyclone overflow was analysed to quantify the effect of each variable on the response along with their order of significance. From this study, individual and interactional effects of parameters on the recirculation load and particle size in sizing cyclone overflow have been assessed. The data have been used to identify the process optimization at plant scale to reduce the power consumption, recirculation loads 450 % reduced to less than 350% which enhanced production and power consumption.

Keywords: Iron ore, recirculation loads, optimisation, interactional effects, plant trial

Rheological Properties of Individual Coals: A Real Time Data used for blend Formulation, Case Study of Rourkela Steel Plant

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Coal fluidity is an important coking property which highly influences the coke quality. Coke quality is a significant factor affecting blast furnace performance with respect to BF production and coke rate. Coal blends are generally prepared as per the available coals on individual coal data like Ash, VM, and FSI. To understand the effect of coal fluidity on coal blending and thereby the coke quality, studies have been conducted using the industrial scale coals and coal blends. In the present study, beyond the regular coal data, rheological data of individual coals have been used for blend formulation. Coke Ovens at RSP use coal from 8-10 different sources for coke making. Large variations in incoming coal properties have resulted in corresponding variations in coal blend and coke quality. The coke quality parameters like average Micum Indices M10 and M40 were 9.3 & 77.5 respectively during a trial period of 4 months. Coal characterization and plastometric properties of individual coal were carried out. Coke quality parameters have been monitored continuously and fluidity testing of individual coal and coal blend were also carried out on regular basis. After revising the blend composition on the basis of test results, it helped in improvement of

coke quality parameters like M_{10} (avg. 9.3 to 8.2) and M_{40} (avg. 77.54 to 79.4) which got reflected in reduction in coke rate of Blast furnaces at RSP.

Keywords: Coal Blend, Fluidity, M_{40} and M_{10}

CFD Modelling of Flow of Slurry through Pipelines

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The flow of non-settling slurries through pipelines are often encountered in mineral processing industries and the study of such flows is primarily explored using experimental means and Semi-empirical models are used for the prediction of the different parameters required in the slurry flow. Assuming the solids in the slurry pipeline as a continuum, the behaviour of the slurry inside a pipe can be studied using numerical modelling techniques. In the current study, the experimental results published by Ekambara (2009) are simulated using CFD modelling. Using a two-fluid Euler approach, the flow inside a pipeline for fine silica particles is being simulated using Ansys Fluent 2020 R2. The solids were simulated using the kinetic theory of granular solids model. The simulations were done in transient mode and the distribution of solids inside the pipeline were compared with the experimental studies. The effect of different source terms on the distribution and pressure was compared with the experimental results. Among the source terms, only drag and turbulent dispersion were found to have a significant effect on the pipe flow. The drag model used for the simulations were the Gidaspow model and the turbulent dispersion was simulated using the Lopez de Bertadano model. Using the Lopez de Betradano model, a tuning parameter was found to be required to be input in the model. The same tuning parameter was found to give good predictions for variation in the solid content from 10 % to 45 % by volume for the same pipe diameter and slurry velocity.

Feasibility Study on Installation of 350 TPH Coal Handling Plant in Kathautia Opencast Coal Mine: An Overview on Moisture Reduction

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Kathautia Open Cast Coal Mine is one of the captive coal mines of Hindalco Industries Limited with the coal having total moisture (TM) at an around 25%. The main objective of this feasibility study is to establish a coal handling plant (CHP) to reduce such high TM of ROM coal from ~ 25% to ~14-18%. Control measures on TM can be done with the reduction in surface moisture and for that necessary field test with various size fractions along their surface moisture has been determined. The proposed CHP has been conceptualised and all individual equipment have been sized based on test results and with that considering seasonal fluctuations in production levels from the mine, throughput of the CHP is considered of 350 TPH. In the proposed system of CHP, the ROM coal will be first received at the Ground Hopper which will be transported to Dry Sizing Screen via conveyor belt to separate out (-50 mm) fraction which will further quench in water in a feed spout and fed to a Desliming Screen. The aperture of the screen is 1mm and therefore material having (-1mm) sizing will be send to the thickener and coal having (+1mm) will move to the centrifuge dryer. The Centrifuge output shall contain around 6% surface moisture and the total moisture will be ~14%. The coal with (+50mm) passing out from Dry Sizing Screen will further fed to double roll crusher and the throughput coal has a predicted total moisture of 15%. Overall projected TM of the throughput coal will be ~14%. The CHP is designed with close circuit water system to ensure zero effluent discharge. Assuming specific power consumption 1 unit/tonne of raw coal, total connected load for CHP shall be approx. 350 KW. Tentative capital cost estimates for this CHP installation is 10.88 Cr.

To Enhance the Operational Efficiency of Blast Furnaces Through Standardization of Fine Coal Characterization

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Pulverized coal injection (PCI) is used in blast furnaces tuyeres in order to reduce the amount of coke required to provide energy and reducing gases for blast furnace operation. In high rates of PCI, due to extremely short residence time available for char combustion in blast furnace, unburned char will be carried from combustion zone to the stack and will compete with coke for CO_2 and hence impacting blast furnace permeability and productivity. Pulverized coal combustion efficiency is an important parameter for higher coal rate injection and avoidance of unburned char formation. In this study reactivity of pulverized coal has been studied for different fineness level of coal and temperature and time of reaction. Reactivity apparatus has been developed inhouse by customization of tubular furnace and coke reactivity apparatus to measure reactivity of pulverized coal. Standardization of testing method of pulverized coal with laser particle size analyser for size analysis has helped in understanding distribution of ultra-fines particle and impact on coal reactivity.

Keywords: Unburnt Char, Coal reactivity, Laser particle

Characterisation Studies on Iron Ore Pellet Concentrate Fines for Feasibility of Pressure Filtration Test

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Iron ore is the prime raw material for iron making. India aiming for 300 MT production by 2030 and the challenges like depletion of high-grade iron ores and high alumina & LOI and soft type of iron ore fines is the challenge for meeting the pellet plant requirements. Filtration is the major unit operation between beneficiation plant and pellet plant converting slurry concentrate into dry concentrate which is the major challenge for maintaining the moisture in pellet concentrate. Lack of process characterization data of the iron ore fines based on the granulometry, texture, mineralogy, physical, chemical, properties which is one of the hindering factors for lower performance and quality rate. In this paper an attempt has been made to understand the behaviour of medium grade iron ore fines before feeding to filtration equipment. Preliminary studies carried out on iron ore fines such as XRD, XRF, mineralogical studies and particle size analysis. Based on that test works were designed and carried out for achieving the better optimized moisture in filtration discharge to reduce the fuel, bentonite consumption and higher productivity at pellet plant. The tests revealed that the predominant phases are kaolinite and gibbsite are major minerals for higher LOI and alumina and increase in the proportion of this material in pellet concentrate which requires higher air-drying time and air pressure for lower moisture and low throughput.

Keywords: Pellet concentrate, alumina and LOI, XRD, XRF, Air drying time

Study on Effect of Coal Blend Dilatation on Coke Quality and Oven Safety

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Coke quality is largely reliant on coal blend quality in coke making. The blending of coals as practiced for stamp charged coke making is determined by technical as well as economic factors. In stamp charged coke making, push force is a key process parameter for oven health and smooth operation of coke oven battery which is mainly affected by dilatation behavior of coal blend. The present study investigates the relation between dilation characteristics of the coal blends, coke making process parameters and physical and mechanical strength of metallurgical coke. The behavior of different coal blends has been studied to determine the effects of dilation of coal blend on coke Micum indices (M40, M10) and push force. The study confirmed that dilatation has significant impact on push force and coke quality. The influence of other important parameter on coke quality and oven safety also studied in this study.

Keywords: Stamp charged coke making, Micum Index, dilation, coal blend, push force

Enhancement in Fe (%) in Iron Ore Pellets and Reduction of Bentonite addition by using Organic Binder

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Historically, bentonite has been used in the agglomeration process from the beginning of iron ore pelletisation as a binder. In this paper, the performance benefits obtained is discussed when bentonite was partially replaced with an organic binder. The totally synthetic binders are used in conjunction with partial bentonite, limestone and anthracite coal. The benefits of organic binders are improved metallurgical parameters of the fired pellets, especially the reducibility, which results in more efficient use of gases in the Blast Furnace; reduced silica in the pellets. A lower silica pellet reduces slag in the Blast Furnace; indirectly in the enhancement of Fe (%); increased production in both the agglomeration/induration and steel making processes; and a decrease in coke consumption. In Pellet Plant#02 (JSPL, Barbil-Odisha), the Organic Binder is being added in the mixer in powder form prior to the ball formation. The organic binder is a polymeric material. Prior to taking plant trial, laboratory scale trials have been done using Inconel baskets and the results were found satisfactory. The results were also found satisfactory in the plant trials with respect to agglomeration, surface quality and heat-hardening of green balls in indurating furnace. Apart from the above benefits a significant cost saving achieved with 60% reduction in bentonite.

Keywords: Pelletisation, Agglomeration, Induration.

Blending, Processing and Pelletization of Low-Grade Iron Ore: The JSW Context

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Iron ore is the key raw material for steel production and its grades are very important with respect to techno-economic aspect of steel production. The limited reserves and the rapid depletion of high-grade iron ore due to the increased demand in steel market is a matter of concern. To address this, JSW Steel Limited is actively seeking ways to use low-grade iron ore to fulfil its demand and sustain availability of high-grade iron ore fines (IOFs) for a longer period. Indian fines typically contain 57% Fe but can go as low as 54% and as high as 61-62%. The ores have a wide range of gangues like alumina, silica, and manganese oxide. This requires a proper blending of different ores for the optimization of iron quality and production costs.

Vijayanagar Works at JSW Steel Limited, operates three units of pellet plants with a combined capacity of 16 MTPA to support hot metal production of 12 MTPA through COREX, Blast Furnace (BF) and 1.2MTPA Direct Reduced Iron (DRI). Blending of the iron ores is ensured at yards through a twin boom stacker-reclaimer, which are fed for dry grinding route and through beneficiation plant for wet grinding route. Optimization of circuits at beneficiation stage regulates the parameters of concentrates e.g. size, upgradation and losses. Subsequent process of pelletizing and induration are tweaked to achieve respectable cold strength and hot temperature properties, which are suitable for BFs as well as COREX and DRI routes.

This paper briefly outlines the necessity of blending, relevance of beneficiation and Induration aspects of low-grade iron ores to make them suitable for pelletization in a techno economic and environmental-friendly manner.

Keywords: Pelletization, Low Grade Iron ore, blending, beneficiation, Induration, Cold compressive strength.

New Opportunities for recycling LD Sludge in an Integrated Steel Plant

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Most of the solid wastes such as sludge, slag and dusts generated at Tata Steel in various ironmaking processes have been traditionally consumed in the sinter-making process. One such waste generated inside the plant is the LD sludge which is a by-product of steel making process. Since, it contains an appreciable amount of Fe (around 63%), it cannot be discarded and is being recycled through sintering route. The fineness of LD sludge (55% < 0.15 mm) suggests that it can be used as the pellet feed by replacing a part of iron ore in iron ore pelletizing process. Preliminary characterization studies for LD sludge was conducted and its use in pilot scale was tested under simulated iron ore pellet plant conditions. The results were encouraging as there were no detrimental impact on pellet quality and productivity under normal pellet operation.

Need of Pelletization and Mecon's Role

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Huge quantity of iron ore fines is being generated at different mines head including low grade fines during mining operation which consists also considerable amount of ultra-fines (<1mm). It is difficult to utilize this material in sinter plants due to process limitation in sintering route. In view of this, iron fines at mines head mostly remains un-utilized, resulting accumulation of fines at different mines head.
Further, reserve of good quality iron ore is fast depleting and supply of quality raw materials to steel plants has become a real challenge. Iron ore beneficiation route is emerging out as a pre-requisite wherein substantial quantity of ultra-fines (in the form of slimes) are also generated, having considerable Fe value and are dumped in tailing ponds in the mines. During present practice

of iron ore washing at different mines, slimes are also generated and dumped in tailing pond. The tailing ponds are becoming full, started over-flowing in many mines and gradually, it is becoming difficult to dump fresh slimes. Since, slimes are having the 'Fe' value as high as 55 -57%, the same also can be used in iron making process after due beneficiation.

Besides space constraint, accumulation of dumped fines & slimes over the years are causing great environmental threat in terms of air & water pollution in the mines and surrounding areas. It is becoming difficult to get a new area for dumping of fines & slimes as it requires fresh forest and environmental clearance. Emphasis on minimizing the pollution and environmental impact needs systematic planning of process route and usage of raw material which shall create minimum footprint on the environment.

The distinct advantages of pelletisation are that it requires certain fineness of iron ore for making green balls of adequate strength during pellet making. This will facilitate gainful utilisation of ultra-fines/ slimes (directly or through beneficiation, depending on the Fe content) accumulated at mines head/ slime ponds over the years. Further, to achieve higher productivity, use of agglomerate (pellet & sinter) as a prepared burden in blast furnaces is a world-wide practice and we should also follow the same charge mix combination as it gives some distinct advantages in blast furnaces.

In view of this, our country should have more pellet plants in order to ensure consistent supply of quality burden materials in iron making units in the form of pellets, as well as to convert accumulated low grade and other dumped fines/ slimes into valued product, which otherwise are lying idle and causing various environmental problems.

MECON's credential in pelletization, specifically in large size pellet plants (approx. 4.0 Mt and above) covers comprehensive engineering services in recent past for some of the large size Pellet plants namely BPSL- 3.85 Mt/year, BRPL- 4.0 Mt/year, JSW Dolvi- 8.0 Mt/year & JSW VJNR- 8.0 Mt/year, out of which Pellet plants of JSW group are largest in India. In both BPSL/ JSW Pellet plant projects, beyond conventional consultancy & engineering services, MECON also rendered certain key services to complement limited basic engineering arranged by Client for the Pellet plants of BPSL and JSW group.

With the knowledge gained over the year, MECON has become a frontline engineering, consultancy and contracting organization and is capable to provide full range of services required for setting up of pelletization projects from concept to commissioning including EPC execution. Further, through the association with installation of country's majority pellet plant installations, MECON is not only up-to-date with latest/ developing technology in the field of pelletization, but also familiar in working with reputed technology suppliers and carry out basic & detail engineering in shortest possible time & in cost effective manner.

Recently, MECON has carried out in-house design development of modular 1.2 Mt/year Pellet plant based on travelling grate technology, to ensure availability of indigenous technology to various potential entrepreneurs. The design includes complete basic engineering, detail engineering and manufacturing drawings of critical process equipment/ technological structures like Indurating machine, Indurating hood & furnace, Process gas ductwork etc. Provisional patent for MECON's designed 1.2 Mt/year Pellet plant has been awarded.

Optimisation of Coke Making Operations to Reduce Coke Spillages

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JSW Steel Ltd. Vijayanagar, operates 8 stamp charged recovery coke oven batteries with a capacity of 3.4 MTPA. Traditionally most of the recovery coke oven batteries around the world are top charged. The typical charged coal would be levelled by means of a leveller and would attain a bulk density of approximately 0.85 – 0.9 t/m^3. The coal occupied the entire free volume inside the oven taking support of the oven doors till the height of the leveller. Oven temperatures played a significant role in controlling coke spillages as increase in the temperatures of the end flues would burn the carbon and create voids to make the coke face unstable. As a result, the face of the coke would fall when the door is opened during pushing, causing a huge spillage affecting equipment heath and delays during operation. As Recovery operations shifted from top charged to stamp charged having bulk density of more than 1.14 t/m^3. Presently along with control of end vertical temperatures, the stability of the coal cake inside the oven is equally important. It has been observed where the Coal cake rest on the oven door on the coke side making a V-Notch in the coal cake near the end verticals after charging. This leads to coke spillages even when the end vertical temperatures are within the limits. On the Pusher side it was observed that the stability is better because of trussle support resulting in negligible coke spillages compared to coke side. The paper details the observations made during the plant trails to reduce coke spillages up to 50% by optimising coke making operations like coal cake making, coal charging & carbonisation.

Keywords: Coal cake stability, Coke spillages, Recovery Coke ovens, Stamp Charged, Top Charged, Bulk Density.

Wollastonite (CaO.SiO2) as a CaO Source in Iron Ore Pellet Making

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The quality of iron ore pellet largely depends on the type and amount of slag bonds formed during induration. The nature of iron ore, fluxes, and binders plays a major role in slag bond formation. In this study, the wollastonite addition on the properties of iron ore pellets is studied. The pellets are prepared in a lab by replacing limestone with wollastonite at different dosage levels. A reference pellet is prepared under typical plant conditions, and the properties of the reference pellet are considered as the base value for improving the pellet quality while maintaining the other parameters at an acceptable limit without altering the pellet chemistry. The lab-scale results show that 50% replacement of limestone with wollastonite results in increase in CCS by 30 points and reduction in solid fuel by 20%. Based on results of the laboratory tests, 12 days plant trial taken in two stages with 4500 tonnes of wollastonite. In first set of 2 first two days trial with limestone, wollastonite, and olivine flux combination observed 30 points improvement in CCS, 20% reduction in solid fuel and 0.25 reduction in return fines. In second set of 10 days trial with limestone, wollastonite and pyroxenite flux combination observed 20% solid fuel reduction, 25 MJ/tonne of pellet specific energy reduction and reduction in firing temperature by 20°C.

POSTER PRESENTATIONS

Radar based Coal Level Measurement System for Silos at Coal Handling Plant of Durgapur Steel Plant

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Real time measurement of coal level inside silos is one of the crucial parameters in the operation of Coal Handling Plant (CHP). It is essential to avoid overspill and under-utilization of silos, which causes operational inconveniences. Timely detection of empty or low coal level helps in maintaining desired coal blend composition, which is very critical for coke quality. The arduous environment inside coal silos, which is predominantly filled with coal dust and moisture, inflicts severe challenges for precise level measurement. This accentuates application of latest non-contact radar type level sensors having high transmission coefficient under such exigent ambience. Presence of moving machineries like conveyors, tripper car, etc. requires careful engineering for sensor installation and protection.

A state-of-the-art level measurement system has been successfully commissioned at CHP of Durgapur Steel Plant. The level sensors are based on 80 GHz W-Band radar using frequency modulated continuous wave (FMCW) method. The antenna emits electromagnetic wave at continuously varying frequency, which is reflected by the coal surface and received again by the antenna. The transmitter electronics calculates the silo level based on frequency phase shift and travel time of wave. A special mounting enclosure has been designed to facilitate precision angle adjustment and to provide protection to the sensor against any mechanical damage and corrosion. The system provides real time display of coal level at silo top. The level measurement data are transmitted to dispatcher control room through remote PLC and fibre optic network. This enables CHP operators with real time data and HMI of coal level and helps them in regulating silo weigh feeders. The data is also transmitted through FO cable to another control room meant for monitoring incoming coal wagons. The level measurement system is integrated with ERP system of DSP.

A Case Study on High Phosphorous Content in Manganese Ore of Keonjhar-Bonai Belt, Odisha, India

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Manganese is an essential constituent of steel. So far, there is no technology which can substitute manganese in steel making. The reserve of high-grade manganese ore in India is limited, which is <10% and the overall production is also low and highly inadequate considering the demand in the manganese-based alloy industry. The manganese ore is also having a high concentration of phosphorus > 0.10% which is not good for steelmaking as it deteriorates the mechanical property of the steel. Keeping this in view, a study has been conducted at Joda-West leasehold of Tata Steel Limited to find the reason behind the increase in phosphorous content. The study presents that the waste rock and the iron ore are primarily having less phosphorus, i.e., less than 0.05%. The manganese ore is dominantly having greater phosphorous greater than 0.05%. There exists a strong correlation between manganese and phosphorous. The manganese content is directly proportional with phosphorous content, i.e., as the grade of the manganese ore increases, the phosphorous content also increases.

Application of Statistical Process Control Tools for Problem Solving in Mineral Processing Operations

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Circuit throughput is a measure for production rate in beneficiation plant. Frequent repetitive problems in unit operations in beneficiation plant is a hindering factor for lower circuit tph which will increase power, water and spares consumption. This paper summarizes work on the application of statistical process control methods in iron ore beneficiation plant to process data and converting data insights to strategies. This will help in improving plant reliability and identifying

the repetitive failures is the objective of the work. Data analysis carried out for identifying the root causes on following unit operations – crushers, wet screens, linear screens, sizing and desliming cyclones, vertical and horizontal high gradient magnetic separators, pressure filters and thickeners etc. The potential root causes are, wet screen mat damage failures, linear screen scraper adjustment and wash water flow adjustment, classifier feed density control, pump V-belt failures, conveyor tripping due to overload, higher density in cyclones and underflow jams, spiral concentrator distributor levels. After identification of potential causes, strategies were developed for addressing the repetitive problems. Primary and secondary, tertiary causes were categorized and Pareto chart, Y-Y analysis, statistical process control tools used for addressing repetitive failures and failure modes and counter measures were developed for reducing the failures and improving production and quality were addressed which resulted in circuit throughput improvement from 170 tph to 210 tph.

Keywords: Statistical process control, unit operations-Y Analysis, root causes.

Process Metallurgy

KEYNOTE LECTURES

Recent Innovative Development in Agglomeration

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Agglomeration is a very important route to utilize lean grade iron ore concentrate and waste iron oxide fines. Two major routes such as pelletizing and sintering are commonly used at present. Sintering is done for the coarser (majority > 0.5 mm) fines and pelletizing is done for microfine (majority < 45 µm). The sintering process has some restrictions on microfine utilization because it reduces the permeability of the sinter bed and decreases productivity. Pelletizing is a cost-intensive process because of its curing at high temperatures. Although both of the above processes have some limitations, they can be chosen as per their suitability in the steel plant. Because of the shortage of good quality lump ore and high productivity and quality demand in the steel plant, both the techniques are becoming more vital day to day and hence improvement in both the techniques in terms of quality, productivity, wastes and microfine utilization, energy-saving, and pollution control are essential. The present paper will focus on some important development work carried out at CSIR-NML for the above purpose. These include low melting synthetic flux development, improving reducibility and lowering reduction degradation index of pellets, wastes and microfine utilization, etc. Very encouraging results have been found in the developed techniques which have very good application potential in steel industries.

Landscape of Trends and Technologies of Western Pelletizing plants

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High-grade iron ore is one of the keys to decarbonize the ironmaking industry, nevertheless new technologies to adequate upgraded ores to optimize ironmaking operations has already attracted attention for decades, as an alternative to process the concentrates. In South America, notably in Brazil, the large adoption of pelletizing operations started in the ‘60s and evolved into today’s different technology levels, adopting techniques and technologies that are still quite unprecedented in the world. From the adoption of HPGR (high pressure grinding rolls) as an option to optimize the pelletizing process to the refractory optimization and adoption of organic binder in replacement

of bentonite much due to the unique characteristic of ores, litho logical complexity, high hydration, and low liberation granulometry.

The pelletizing process has been proved to be versatile in the raw materials (fuels and binders) to be adopted and capacity to be controlled though advanced strategies and technologies (a dvanced controls and Artificial Intelligence). The operations in Brazil stand out for their transoceanic production, with large-scale plants and best technologies available. However, in a new wave of demand for updating, existing operations have been under pressure to increase environmental controls (e.g. NOx, SOx and dust) and the focus on alternatives that can sustainably reduce CO_2 emissions has become the major challenge for the survival of this operation, which it already has the challenge of seeking a substantial reduction in production costs.

More recently, new agglomeration alternatives have been investigated and the rapid adoption at the industrial scale are remarking innovating the market and have a great potential to change the industry.

Industry must begin using Coal through Gasification Technology

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The energy demand of India is continuously increasing. Coal is the major fossil fuel in India and continues to play a pivotal role in the energy sector. India has coal reserves of 350 billion tonnes and is the largest producer and supplier of coal. Coal meets about 60% of the commercial energy needs and about 70% of the electricity produced in India comes from coal, and therefore there is a need for technologies for utilization of coals efficiently and cleanly. Coal gasification is environment friendly and carbon emissions are minimal. The gasification technology will also help India overcome the shortage of oil, gas, methanol, ammonia, urea and other products, making the country Aatmanirbhar. The domestic industry should use coal through the gasification process. Burning coal in open furnaces should be stopped. When we gasify coal, carbon emissions are minimal. Coal can be converted into syngas which can be used for producing power, petrol, diesel and other petroleum products, which can reduce dependence on crude oil imports. Syngas can be also used in sponge iron making, by the glass and ceramic industry and even in cooking. Further, India can produce the cheapest hydrogen through the coal gasification route. The government has set a target of gasifying 100 million tonnes of coal. This should be increased to 500 MT. Jindal Steel and Power Limited (JSPL) is already using the coal gasification technology at its Angul plant in Odisha. It is India's first and the only plant producing steel from swadeshi coal using the coal gasification technology.

Overview of Mechanisms of Pellet Degradation in DRI Process

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With increasing popularity of DRI process and simultaneous deterioration of iron ore quality, it has become critical to understand the behaviour of pellets with varying iron ore source and quality on DRI process and product quality. Further, literature on mechanism of pellet degradation during the reduction process in DRI furnaces is not as abundant as it is for the blast furnace. In this presentation, mechanisms of pellet degradation during reduction in DRI process will be discussed including the effect of pellet quality, temperature in various zones in DRI furnace, gas composition, metallurgical changes and mechanical stress. Various methods of pellet testing will also be compared for simulating the DRI process in the lab scale.

Rebuilding the Airplane While in Flight – Decarbonizing Steelmaking in India

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The iron and steel sector is one of the top three sectors contributing to CO_2 emissions in India, as well as globally. India is the world's third-largest emitter, with 3.6 gigatons equivalent of CO_2 across all sectors. More than 25 nations have set up roadmaps to decarbonize by mid-century and this subject has become a burning topic in India as well. In the Indian steel industry, while some reduction in CO_2 emission is possible using upgradation strategies, full decarbonization can only be made possible by utilizing the alternative DRI-EAF route using green H_2 generated from renewable energy.

While hydrogen is a budding opportunity to facilitate decarbonisation, the technology to produce green H_2 is currently unaffordable. However, by 2030, with the projected fall in renewable energy and electrolyser costs in India, green H_2 would pose a strong business case in terms of both cost and scale to produce green steel competitive with steel from traditional fossil fuel. The green hydrogen-based DRI–EAF route promises unsurpassed benefits to replace the conventional BF-BOF route.

Steel producing facilities have lifespans of 50+ years with investment planning horizons of 10 to 15 years. This, coupled with the fact that they already exist and there are newly planned large integrated facilities, means the shift towards hydrogen-based steel cannot happen overnight. The road map needs to comprise of spaced-out actions and milestones for a gradual transition to reach the goal without interruptions in business, heavy CAPEX / OPEX penalties, or loss of revenue.

However, to make the steel industry carbon neutral, an immediate shift to green H_2 is not required. Midrex has designed a 3-step transition to move gradually towards hydrogen-based steelmaking. This strategy envisages starting with a natural gas-based plant with built-in flexibility to proceed through the steps as greater volumes of affordable hydrogen become available before finally switching over to 100% H_2 with MIDREX H_2.

Fundamental Understanding on the use of Different Carbon Sources in the Alternative Ironmaking HIsarna Process

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HIsarna process offers a low CO_2 emission alternative to the blast furnace for hot metal production. This new smelting ironmaking technology is flexible in raw materials such as substitution of coal with biomass. The reduction process is conducted through multiple mechanisms within the smelting reduction vessel (SRV) including reactions of the gaseous products from thermal decomposition of carbonaceous materials with iron oxide in slags. Since the construction of the HIsarna pilot plant (at the capacity of 8 tons of hot metal/hour) in Tata Steel site in the Netherlands in 2010, several successful trial campaigns have been completed using thermal coals. Campaigns to partially replace coal with biomass and charge steel scraps in the SRV were also successfully conducted since 2018 demonstrating further significant CO_2 emission reduction, however, the change in process performance due to biomass injection was noticed.
To advance the fundamental understanding of the use of different carbonaceous materials in the HIsarna process and help optimise the carbonaceous material selection, a systematic research has been carried out for different carbon sources under simulated HIsarna thermal conditions. The thermodynamic and kinetic behaviours of the carbon-gas-slag-metal systems have been studied for coal and biomass injection in laboratory experiments. This talk will introduce some research findings from this systematic research, including slow/rapid devolatilisation of the carbon sources injected, structural characteristics of the resultant chars, and slag-carbon reactions for coal and biomass.

Performance Improvements and Innovations in Process Metallurgy through Computational Fluid Dynamics

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Several processes in steel industry involve a variety of multiphase flows; often accompanied by heat transfer, metallurgical reactions and phase change. For example, solids handling in raw materials processing, complex flow of coal, iron ore, liquid metal and slag in a blast furnace, primary and secondary steel-making processes employing BOF vessels and ladles, flow in a tundish, slab casting, etc. In addition to the process kinetics and operating conditions, performance of several of the aforementioned processes is governed by complex multiphase flows inside the process vessels. To innovate new process designs or to improve the performance of existing processes, it is imperative to understand the multiphase flow behaviour and its interplay with the transport processes and reactions. Measurements of fluid flow and transport processes in real-life process vessels are challenging and sometimes not possible due to harsh operating conditions. Modelling and simulation tools based on the Computational Fluid Dynamics (CFD) approach are extremely useful for performance optimization of such complex processes and also to realize process innovations. In the present talk, a brief overview of applications of CFD for performance optimization in the area of process metallurgy will be presented. Further, some of our recent work carried out at IIT Delhi on the development of CFD models to simulate gas-liquid flow and liquid-phase mixing, without and with slag layer, in the scaled-down model BOF vessel and ladle under cold flow conditions will be presented. The validation of CFD models using the advanced flow measurements such as Particle-Image Velocimetry (PIV) and Laser-Induced Fluorescence (LIF) will be discussed. Finally, the applications of such experimentally-validated CFD models to improve the understanding of multiphase flow processes and to optimize the liquid-phase mixing in the BOF vessel will be discussed.

Modern Tools for Steel Research and Process Improvement

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Our understanding of and ability to quantify steelmaking reactions have been enhanced by the ongoing development of computational and chemical analysis tools. In this presentation, my focus is on ladle refining, and in particular the changes in steel and inclusion compositions. The sizes and chemical composition of inclusions can be measured rapidly using automated scanning electron microscopy. Such measurements support quality control, and also validate kinetic models of steel refining. The conceptually simple kinetic models rely on known steel solution thermodynamics, together with calibrated mass transfer coefficients. These models predict how inclusions approach equilibrium with the ladle slag over time, answering questions such as how the depth of steel oxidation affects the rate at which alumina deoxidation products transform to spinel, and beyond spinel to periclase (MgO). Data analysis tools, combining plant data from hundreds of heats with the underlying reaction principles, provide new insights into what really limits steel refining: kinetics, thermodynamics, for process disturbances such as reoxidation. These three approaches – automated inclusion analysis, rapid kinetic models, and data analysis – are amongst the powerful tools that allow ongoing optimization of steel refining.

Influence of Physicochemical Properties of CaO-Al_2O_3-MgO based Slags on Cleanliness of Al-killed Steels in Secondary Refining and Continuous Casting Processes

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The physicochemical properties of CaO-Al_2O_3-MgO based molten slags are highly important to understand and to control the complicated phenomena occurred in refining processes such as ladle furnace (LF), Ruhrstahl-Heraeus (RH) vessel, and in tundish during continuous casting of Al-killed steels. Specifically, Al_2O_3 (cluster) and $MgAl_2O_4$ spinel are harmful inclusions not only affecting the surface quality of semi-products but also resulting in the clogging problems. The probability of spinel inclusion has been known to be strongly affected by slag chemistry and deoxidation practices. Moreover, the thermophysical properties of the CaO-Al_2O_3-MgO-SiO_2-CaF_2 slag such as viscosity and interfacial tension should also be carefully controlled to suppress the formation of this harmful inclusion at the LF stage. The ultra-low carbon Al-killed (ULCAK) steels are produced via RH process, which employs the CaO-Al_2O_3-FeO-MgO-SiO_2 slag. During RH process, the deoxidation, inclusion removal and reoxidation reactions are simultaneously occurs, and the related metallurgical phenomena are strongly affected by the physicochemical properties of RH slag.
Alternatively, tundish metallurgy has been issued because it is the final reactor for controlling the steel cleanliness in view of the reoxidation phenomenon of molten steel. The reoxidation is experienced by the contamination of molten steel not only due to air entrapment but also due to slag-metal reaction. There is less investigations for the latter compared to the former. The rice husk is widely used because of its high thermal insulation characteristics. However, it causes the silica pick-up to the molten slag pool in tundish, resulting in the changes of physicochemical properties

of tundish slag. Consequently, in this paper, the recent issues for the physicochemical properties of CaO-Al_2O_3-MgO based slags will be discussed in terms of clean steel production technologies.

Approaches for Differentiation and Value Creation in Steelmaking

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Continuous improvements and value creation are key ingredients for sustainable steelmaking which converts and customizes a generic product like hot metal into customer specific steel orders. Customer requirements w.r.t. steel cleanliness and residuals are becoming increasingly stringent. This calls for through process optimization of the ironmaking-steelmaking production chain, besides modifications and finetuning of primary and secondary steelmaking practices.

Hot metal chemistry is unique at Tata Steel, Jamshedpur works in terms of high P and low Si (i.e. lower Si/P ratio). High P (Phosphorus) in the indigenous raw materials (e.g. iron ore and coal) results in higher P in the hot metal. Of late, lower coke rate operation in the blast furnaces has led to lower hot metal Si (Silicon). Lower Si/P ratio has adversely affected primary steelmaking in the last couple of years. Extensive trials recently with optimum hot metal chemistry showed encouraging results leading to win-win through process optimization in the ironmaking – steelmaking value chain.

Steelmaking also generates bulk wastes e.g. LD slag, LF slag etc. These wastes contain valuable elements and their recycling not only creates value but also ensures sustainable operation. LF slag recycling has been successfully implemented at Jamshedpur works in recent times. This has resulted in lowering fluorspar and lime consumption at LF without affecting its operational efficiency. Similarly, successful trials of new DS (De-Sulphurizing) compounds shows promise to reduce normal DS compounds e.g. CaC_2 and Mg. Innovative trials are in progress to reduce or eliminate GPC (Graphitized Petroleum Coke) and Fe-P (Ferro-Phosphorus) usage in steelmaking. These materials are imported and their replacement with suitable indigenous materials reduce dependencies and aligns with the 'Atmanirbhar' paradigm.

ORAL PRESENTATIONS

Effect of Temperature and Reducing Conditions on Physico-chemical Properties of Sinter

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Reducibility of charged burden material in a modern high capacity blast furnace is an important lever for higher hot metal production and lower fuel rate. Sinter constitutes 40–80% of the iron bearing burden material in the modern blast furnaces. Sinter reducibility has direct impact in increasing the efficiency of gas utilization inside the blast furnaces. Sinter samples of reducibility index ranging between 65% to 85% have been studied to check the variation in porosity, bulk density and chemical properties before and after reduction at 900 °C in reducing gas (70% N_2 and 30% CO). After reduction, FeO content was found to be increased significantly. Microstructural study has been done on sinter samples with varying reducibility values and increase in acicular ferrite content has been observed in the sinter with higher reducibility index.

Keywords: Sinter reducibility, Microstructure, Porosity

Improvement in Pellet Quality in Straight Gate Induration Furnace

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Fines generation during the transit of pellets due to inconsistent quality is a known problem. It directly affects the available pellets for next processing and further deterioration of pellets during reduction in SIP or BF. There are many factors which lead to the inconsistency in the pellet quality for a given batch including temperature gradient, heating rate variation across the depth of the pallet car, size distribution of pellet, horizontal location of the pellet in a pallet car, channeling of hot gases due to local variation in bed permeability, etc.

One dimensional heat transfer modelling was done to study the temperature difference across the depth. Subsequently, layer-wise sampling was done in the industrial pellet plant to correlate model output with the layer-wise pellet quality. Size-wise sampling of the indurated pellets was done and various quality parameters were evaluated and found to be in good agreement with the published literature. Further sampling was done based on the visual observations to identify the quantity of unfired pellets and characterized. The above findings led to various recommendations for improving the consistency in pellet quality.

Keywords: Iron ore pellet, pellet, tumbler index, abrasion index.

Effect of High Temperature on Interaction between Sinter and Pellet on Softening-Melting Behavior

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A well-designed burden mix is crucial to have a healthy blast furnace (BF) operation and productivity. The mixing ratio of the iron oxide, mainly the agglomerates i.e. sinter and pellet plays an important role in BF process owing to different compositions and metallurgical properties. In this work, a series of experiments were undertaken to evaluate the effect of (i) different ratios of sinter and pellet, and (ii) chemical composition of sinter and pellet, on the high temperature behavior of the burden mix simulating the blast furnace conditions. It was found that high temperature interaction of different constituents resulted in diverse softening-melting behavior, bed contraction and the cohesive zone characteristics. Finally, an optimum combination of burden mix was determined for different cases based on the differential pressure experienced by the sample bed, to have the cohesive zone with least resistance.

Investigation on the Pilot Scale Pelletization Process Using Low Grade Iron Ore

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Indian blast furnaces are fed with lump iron ore (10 – 40 mm size) and sinter as burden. Sinter is a prepared burden, where iron ore fines of size -10 to +0.15 mm are agglomerated using mainly flux and coke. Iron ore fines of less than 0.15 mm are not utilized in sintering technology and hence are mostly discarded as slime. To utilize such rich quality of iron ore mineral particles, pelletization technology has been developed and commercialized in many places. Pellet induration is generally performed in moving grate or grate kiln furnaces, through which pellets are sequentially dried, fired and cooled by direct contact with hot gases of varying flow rates and temperatures. Indian low-grade goethite ore ($FeO(OH)$) comprises a significant amount of chemically bonded water (approx. 6%). During faster pellet induration, this bonded water suddenly gets evolved at a temperature range of 350 to 450 ºC. Hence, some of the pellets get cracked and some of them get disintegrated during induration. In the present investigation, a suitable induration cycle has been developed for pelletization of the Indian low-grade goethite ore to produce commercial grade pellets. Pellet grade concentrate was produced through beneficiation of goethite ore of Bolani mines under Steel Authority of India Limited. Green pellets with a basicity of 0.35 were prepared in a laboratory disc pelletizer. These pellets were then dried, pre-heated and fired in a tailor-made laboratory scale horizontal zone furnace by varying main process parameters such as temperature and soaking time. Thereafter, the experimental data was validated in a pilot pelletization system of capacity 60 kg per batch i.e. a straight grate simulator. Pellets obtained by optimizing the process parameters exhibited properties such as cold compressive strength, porosity, Reduction Degradation Index (RDI), Reducibility Index (RI) in line with the blast furnace grade pellets.

Keywords: Goethite Ore, Pellet Induration, Cold Compressive Strength.

Effect of Mixing Pre-heated Water on Granulation and Iron Ore Sinter Properties

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Granulation of sinter feed mix is one of the most important factors in determining the permeability of sinter bed and sinter properties like sinter yield, tumbler index etc. To improve the granulation of sinter feed mix, various technologies like two stage granulation process, coating granulation process, wet vertical ball mill and use of magnetic water have been reported. In this paper, effect of pre-heated water (30, 60 and 90 °C) on granulation fitness of sinter feed mix was studied using a laboratory mixing drum. Sinter properties were investigated using pot sinter experiments. It was observed that with addition of pre-heated water, granulation fitness i.e. balling index (BI) and granulation index (GI) had increased, indicating that wetting of sinter feed mix had improved significantly. Treatment of sinter feed mix with pre-heated water reduces the surface tension of water and improves slaking of lime. This enables improved binding of small size faction (-0.25 mm), leading to stronger green balls which results in reduced fine generation during charging into the sinter bed. This further leads to the improvement in bed permeability and sinter properties. Enhanced hydration of lime and improved dispersion of water aided in the improvement of GI by 5.3% and BI by 9.7% along with increase in sinter yield by 2.1% and tumbler index by 1.6%.

Lowering the Sinter Return Fines at H Blast Furnace

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Iron ore sinter is a preferred metallic burden for blast furnaces due to its good physical, chemical and metallurgical properties. The smaller size fraction of sinter i.e. minus 5 mm is not charged to the blast furnace as it adversely impacts the permeability and hence the stability of blast furnace. The minus 5 mm fraction which is screened out is recycled in sinter making, which is thus known as sinter return fines from blast furnaces.
The sinter return fines from H blast furnace at Tata Steel Jamshedpur (TSJ) works was approx.

17%. It was decided to lower it by optimizing the process parameters in sintering and also by improving stock house management at the blast furnace. Trials with lowering the sintering rate, optimizing the waste gas fan rotation speed and reducing the heat input to control the product sinter temperature were carried out. The return fines came down to the level of 13-14% under the new optimized operating regime.

Based on the increased understanding of different parameters influencing return fines, an online model was developed which takes into account the sintering process parameters, sinter quality and blast furnace stock house indicators such as bin level, screening rates etc. on a real-time basis. The visualization tool helped the operators to identify those parameters which influence process and quality deviations and take corrective actions to bring down the generation of sinter return fines. This model has been successfully implemented at sinter plant #4.

Factors affecting Sinter Bed Permeability and its Impact on Other Process Parameters at Sinter Plant-3

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The sinter quality has become very important with its increased usage in large blast furnaces. The sinter production rate is directly proportional to the vertical sintering speed (VSS) in the sinter bed from top to bottom. The movement of high temperature flame front depends upon the air flow in the sinter bed which is a function of permeability of sinter bed and the available suction under the bed. The flame front speed and gas flow through the bed govern the temperature profile through the bed. The permeability of the sinter bed is a function of granulation efficiency of the sinter mix. The objective here is to generate data and establish a co-relation between granulation index (GI) and permeability of sinter bed on productivity and quality of sinter. A number of trials were conducted for sinter mix granulometry, air filtration velocity and available suction at SP-3 to determine GI and bed permeability. From data analysis, it was found that permeability of sinter bed increases with increasing GI upto a value of 1.89 and decreases afterwards. With increasing moisture, GI increases due to reduction in amount of very fine particles in sinter mix. The bed permeability decreases with moisture exceeding 9.77%, even though granulation increases. Sintering time decreases with improved bed permeability. The best sintering time of 32.49 min was achieved with permeability of 20.62 JPU and machine speed of 2.77 m/min. VSS decreases with an increase in bulk density of material. Highest VSS of 21.54 mm/min is achieved for bulk density 1.48.

Keywords: Vertical sintering speed, permeability, Granulation index, granulometry.

Magnesium Oxide based Product Spray on Sinter to Reduce RDI

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Increased sinter burden with development of sinter return fines charging at blast furnace required to lower target sinter CaO from about 12.5% to 11.5% at sinter plant #2 (SP2). At lower CaO, sinter RDI deteriorated without chaning other parameters. This led to the proposal for a trial of magnesium oxide (MgO) based coating over sinter surface. MgO reacts with iron oxide (Fe_2O_3) of sinter balls and forms a complex with iron oxide which can inhibit the advancement of hematite to magnetite transformation and thus reduce the RDI of sinter.
The objective of the paper is to assess the impact of MgO based product coating over sinter on RDI at various dosing rates. Altogether twelve sinter RDI tests were conducted within the same batch of sample. Five MgO solutions were freshly prepared with concentration varying from 1 g/l to 30 g/l in water and compared with a base case. Of these, six RDI tests were done without any rotation (plain) and six with rotation in JIS RDI drum. This was done to simulate the condition of MgO coated sinter transfer by conveyor belt.
In case of plain samples, a maximum drop of 4.7% (from 26.5% to 21.8%) in RDI was observed with 30 g/l coating. With rotated samples, a drop of 1.7% was achieved with coating concentration of 10 g/l. Overall RDI was lower by 3% in case of samples rotated in JIS RDI drum as compared to plain samples, possibly due to enhanced mixing of MgO coating during rotation.

Keywords: Magnesium Oxide (MgO), RDI, Sinter Coating.

Influence of Sinter MgO on Flame Front Properties and Sintering Process

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MgO is detrimental in sintering process however, it is added through sinter to maintain blast furnace (BF) slag fluidity. Optimisation of MgO content is necessary for improving sinter quality and productivity. MgO is charged through dolomite which acts as heat sink and reduces the sintering speed. The aim of the present work was to measure the influence of %MgO on flame front property and other properties of sinter.

Iron ore from four different sources namely Bolani iron ore mines (BIOM), Kiriburu iron ore mines (KIOM), Meghahatuburu iron ore mines (MIOM) and Barsua iron ore mines (BARS) was used in pot sintering experiments. Other raw materials e.g. coke breeze, flux etc. have been collected from one of the SAIL plants. Sintering charges were calculated targeting %MgO in sinter to vary in the range of 2.2% to 3.0%. For understanding and measuring the flame front movement, sintering experiments were conducted in transparent pot, which is first of its kind in India.

As MgO in sinter increased from 2.2 to 3.0%, the flame front movement was gradually reduced to 30%. Accordingly, vertical sinter speed (VSS) also decreased gradually with a reduction in sinter productivity. Flame front widening by 10-15% with increasing MgO was visually observed. This was found to be responsible for lowering of VSS and sinter productivity. With increasing MgO in sinter, time temperature curve shifted rightwards, i.e. away from the vertical axis. The slope of cooling curve decreased when MgO was increased beyond 2.7%, indicating a larger time required for cooling of sinter bed. Sinter with MgO content 2.3 - 2.4% was having lowest specific coke breeze consumption, beyond which it was increased. Generally, sinter tumbler index (TI) deteriorates with increasing MgO percentage. MgO in 2.3-2.5% range was found to be ideal for achieving higher TI value.

Keywords: sinter MgO, flame front movement, productivity.

Mitigating the Detrimental Effect of High Alumina in Sinter Making

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The adverse role of alumina in high temperature property of sinter viz reduction-degradation index (RDI) is a known fact. Increase in alumina content of the sinter beyond 2 wt.% decreases the sinter strength. It increases the RDI, and as a result, coke rate goes up. For maintaining the same RDI with increased alumina content, amount of flux need to be increased which leads to higher slag rate and lower productivity in blast furnace. The alumina content of iron ore fines, together with the process conditions that sinter blends are subjected to, plays an important role in forming the primary melt during the sintering process and consequently determines the sinter structure and quality. Therefore, considerable emphasis is given on the chemical composition and consistency of iron ore fines, especially in terms of alumina content. However, due to the limited reserves and increasing depletion of high-grade iron ore resources, the alumina content of iron ores is expected to increase gradually.

Recently, sinter plants at Tata Steel have witnessed a significant increase in alumina level in sinter (from 2.4% to 2.9%). Thus, the challenge was to maintain the sinter quality at lowest possible carbon rate. Hence, various measures were undertaken to control the carbon rate increase by 3.5 kg/t (59.5 kg/t net sinter to 63 kg/t net sinter) as against the expected increase of 7.5 kg/t (1.5 kg per 0.1% increase in Al_2O_3). The ignition intensity was increased from 2.96 to 3.06 MJ/m^3. Furthermore, flame front speed (FFS) and machine speed was reduced with simultaneous increase in charge to maintain the sinter productivity.

This paper discusses the measures to counter the adverse impacts of alumina on sintering performance. The mechanism responsible for the deterioration of RDI of sinter due to the increase in alumina content are also reviewed.

Optimize the use of Pyritic Ashes in Sinter Plant

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JSW Steel Dolvi works operates two sintering strands (198 m^2 and 224 m^2) with 100% low grade Odisha fines. The biggest challenge was very high alumina load in Blast Furnace -1 (BF-1) with a slag rate of 470 kg/thm. To offset alumina in sinter and control the slag rate in BF-1, higher Fe (65-66%) and lower alumina (0.3-0.7%) material called pyritic ashes was introduced in sinter feed mix. Pyritic ashes contain very high sulphur (0.8-1.2%) and Zn (0.1-0.2%). Sinter bed permeability was dropped due to higher microfines (-0.15 mm >97%) in pyritic ashes. As a result, productivity and cold strength of sinter dropped. Alumina content in sinter was reduced by 0.2% but S and Zn in sinter increased up to 0.011% and 0.004% respectively. Due to increased level of Zn in sinter, zinc load in BF-1 was increased from 54 to 120 g/thm. SO_x level in stack increased up to 522 mg/Nm^3. Considering above facts, pyritic ashes in sinter feed mix was restricted to 8%. This led to improvement in both hot and cold strength of sinter.

Keywords: Alumina, Sulphur, Slag rate, Sinter bed permeability, SO_x, Cold strength & Hot strength.

Enhanced Simulation of Sintering Process in an Experimental Pot Sintering Unit through Innovative Measurement, Monitoring and Control System

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A pot sintering equipment is used to carry out pilot scale sinter making, by simulating the real plant conditions. The results of the sinter pot test can also be used for sinter process optimization. Sinter pot experiment involves measurement of parameters such as temperature, pressure, air filtration velocity, gas flow and component analysis.
Pot sintering facility at SAIL RDCIS is used to carry out characterization of sinter raw mix of various grades and quality to establish the best practices for sinter making. The facility has been enhanced through in-house design and development of an innovative measurement, monitoring

and control system. The system has an integrated instrumentation scheme specially designed for on-line acquisition of key parameters from sintering experiment. In the plant scale operation steam and hot air injection are an added advantage to improve quality. In line with this requirement, the experimental unit has also been equipped with facility for controlled injection of steam and hot air while carrying trials. The system is equipped with centralized monitoring of the experiment through user friendly HMI screens for remote live viewing of the experiment. Also, the data is recorded in real time for analysis.

The system is regularly and successfully used for characterization of various raw mix samples used for sinter making. Once the sinter is made the same is tested for quality and thereafter the quality achieved can be correlated with the operating parameters measured and recorded, facilitating an improvement in actual sinter making process.

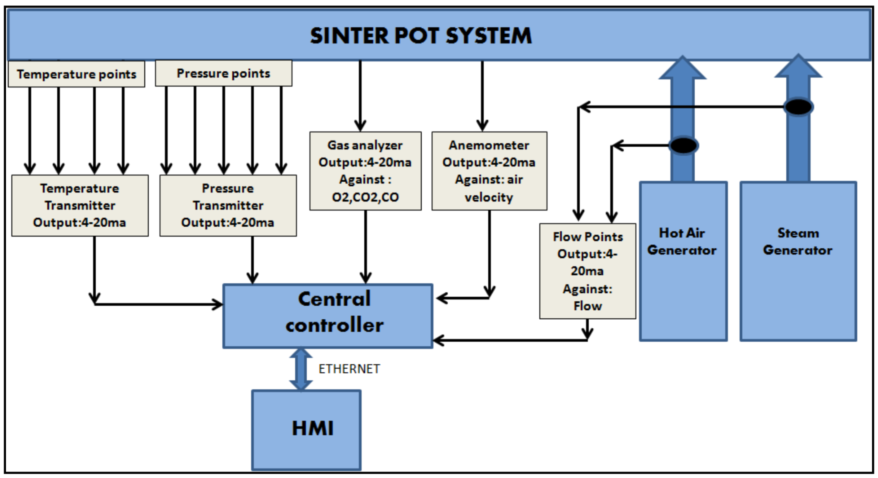

Fig. 1. Architecture of on-line measurement, monitoring and control system

Keywords: Sinter Pot, Raw Mix, Measurement Sensors, Data Acquisition, HMI.

A Study on Critical Parameters of Coke Dry Cooling Plant (CDCP)

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In the coke making process, coking coal is heated in the absence of air to produce metallurgical coke in the coke oven batteries (COB). After carbonisation, the red-hot coke is either wet or dry

quenched. In dry quenching, red hot coke is quenched in cooling chambers using circulating gas. The unit of a coke oven where red hot coke is quenched with inert circulating gas is known as coke dry cooling plant (CDCP).
The coke from CDCP has very low moisture in the range of 0.3-0.5% with better cold and hot strength as compared to the coke produced from wet quenching. However, the limitation of CDCP are low cooling rate, coke floating and burning losses.
In the present work, the performance of the cooling chamber in different SAIL plants was studied and compared. Many operating parameters were monitored and measured to identify the critical parameters which affect the cooling rate of coke. It was found that oxygen equivalent is one of the critical factors which affect the performance of chambers. The reasons for coke floating in chamber was also studied and it showed a strong relationship with coal blend and operating parameters of the coke oven. A lab scale trial was carried out in an in-house developed dry cooling unit to find the relationship between coke quality and coal blend. The results were compared with plant data to find out the reasons for coke floating.

Keywords: Coal Blend, CDCP, Coke Floating, Cooling Rate.

Effect of Volatile Content of Coal on Final Burnout in Raceway

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About 70% of steel production in world is through blast furnace (BF) - basic oxygen furnace (BOF) route. Blast furnace is energy intensive as it accounts for almost 50% of energy consumption in an integrated steel plant. Carbon dioxide (CO_2) emission is a prime concern nowadays with stringent environmental norms and blast furnace is responsible for about 70% CO_2 emission in a steel plant. Effect of coke consumption in blast furnace on cost (around 30% of total cost) & CO_2 emission is well known. It is an established practiced to increase the pulverised coal injection (PCI) to reduce the coke consumption in the blast furnace. Characteristics of the coals used for PCI vary with the source of the coal (e.g. ash, volatile matter, fixed carbon & moisture content). For coal injection moisture content of coal should be less than 10%, Ash content should be less than 10%, mineral content should be less than 11.6%, fixed carbon should be in the range of 45-85% and volatile matter must be in the range of 10-40%. To compare effect of change of coal properties on its de-volatilization and burnout along the tuyere axis inside the raceway, a CFD modelling was done using ANSYS FLUENT. To keep account of turbulence nature of flow k-ε model is used, two-competing reaction rate model is used for coal de-volatilization, field char combustion model is used for coal char combustion. The developed model was validated with the published data of coal

injection test rig and was found to be within acceptable error range. Further, the model was used to compare burnout of coals with varying Volatile content from 12% to 39% and found that % burnout increases with the increase in volatile matter in the coal.

Keywords: PCI, CFD modelling, Tuyere injectants.

Effect of Heating Rate on Rheological Properties of Coal and Coke

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The productivity and coke quality of a recovery type coke oven depends on coal blend composition, operating parameters and heating rate. The coking process is the transformation of coal into coke at high temperature. The heating rate has a strong influence on both plastic stage as well as semi coke stage. It also influences the strength and the fissuring properties of coke. In the present investigation, the rheological properties of coking coals were studied at different heating rates of 3, 4 and 5 °C/min during plastometer and dilatometer tests. Based on the analysis, it was observed that higher heating rate has enhanced the plastic and dilation property of coking coal, resulting in strong effect on coke quality.
To establish the effect of heating rate, pilot oven trials were carried out. The heating rate for carbonization was varied from 2.7 °C/min to 3.3 °C/min in a step of 0.2 °C/min from the coal charging temperature of 700 °C, in first two hours of fixed coking period of five and half hours. To achieve this heating rate, pilot oven wall temperature was varied from 1025 °C to 1100 °C in an interval of 25 °C. The higher wall temperature affected the coke quality in terms of stability, coke strength after reaction and coke mean size.

Keywords: Coke Oven, Plastometer, Dilatometer, Heating rate.

Advance Technological/Process Modifications for Productivity Improvement and Effective Waste Heat Utilization in Coke Plant

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JSW Steel Limited (JSWSL), Salem Works, is the largest integrated special alloy steel plant in India. It operates two blast furnaces with a combined production capacity of 1.0 million tons per annum of hot metal. To cater the metallurgical coke requirement of blast furnaces (BF), a waste heat recovery type captive coke plant with a capacity of 0.5 million tons per annum was commissioned in 2007.

JSW Salem coke plant has faced the challenge of meeting the additional demand of metallurgical coke at optimum cost due to lower pulverised coal injection (PCI) in BF through following initiatives:

- Coal blend cost optimization by using low-cost semi-soft coking coal up to 35%.
- Increase coal input per oven and thereby increasing coke output by adopting new technology in coal charging.
- Improving waste heat gas utilization by modifying the pushing series to maximize steam from waste heat recovery boilers.

This paper describes how challenges were converted into opportunities to make cost-effective coke with a focus on energy conservation in JSW Salem coke plant.

Keywords: Coal Blend Optimization, Introduction of Plate charging, Process Optimization, Waste heat gas utilization.

Improving Coal Combustibility through Injection of Calcium Oxide along with Pulverized Coal Injection at I Blast Furnace, TATA Steel

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Pulverized coal injection has been identified as one of the enablers for controlling cost in blast furnace route of iron making through reduction in coke consumption. However, at higher injection rates of pulverized coal, a significant drop-in replacement ratio is observed across blast furnaces which becomes a major bottleneck for lower coke rate operation and leads to increased off gas dust generation in the downstream. Several works have been carried out in the past to improve the combustibility of coal through catalyst injection which increases the extent of coal dispersion inside blast furnace. Therefore, at I Blast Furnace, TATA Steel Jamshedpur, lime has been injected along with pulverized coal to enhance its replacement ratio. Density of lime particles ranges from 3.2-3.4 g/cm^3 whereas density of coal varies from 1.2-1.7 g/cm^3. Denser lime particles when injected along with coal create scattering effect and lead to increased coal dispersion in the raceway. The injected lime powder through tuyeres has not only improved coal combustibility but has prevented silicon pick up in hot metal through suppression of SiO_2 activity and SiO gas formation in the raceway. Consequently, a rise in coal rate by 5 kg/thm has been realized along with a drop in hot metal silicon content from 0.63% to 0.58% at I Blast Furnace.

Keywords: Blast Furnace, Pulverised Coal Injection, Coal Combustibility, Raceway, Replacement Ratio.

PCI at RINL - Challenging Start to a Promising Journey

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Pulverised coal injection started rather late in RINL blast furnaces i.e. in the later part of 2015-16 because of a variety of reasons. However, even after commissioning and stabilization of the PCI plant, the injection could not be steady and ramped up to the desired level, because of throttling of the furnaces on account of a mismatch in hot metal production and steel melt shop consumption. Frequent stoppage of the furnaces on account of poor off take of hot metal has primarily been the reason for inconsistent and low injection rate. However, with improvement in metal disposal in last couple of years, injection could improve close to 150 kg/thm initially in BF3 and subsequently in BF2 and BF1 with consistent efforts and suitable changes in operating philosophy and practices as brought out vividly in the paper.

Keywords: Blast furnace, Pulverized coal injection.

Operational Experience with Increased Pellet burden JSW BF2

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Agglomerates have been considered as a better iron carrier feed to blast furnace to improve furnace productivity and operational efficiency. JSW BFs gradually reduced the lump C-Ore portion from the IBRM feed from last 3 years by increasing pellet in the burden. With the commissioning of new Pellet Plant#3, the availability of pellet support to maintain the supply chain was enhanced. With the increase in pellet burden from 25% to 35% there has been a shift in furnace gas flow profile, production, techno parameters and hot metal quality. This paper discusses the challenges and operational improvements and production and techno-economic improvements at BF2 only.

BF2 has been designed with working volume of 1462 m^3.

The strategic improvements started from stock house by converting C-Ore bunkers into pellet bunkers and subsequently changing vibro feeder settings and screens, offline model trials to mitigate and control the rolling behaviour of pellet to maintain a desired charged burden top profile, monitoring the gas flow behaviour and burden adjustment for better gas utilisation and fluctuating heat flux. Improvement in blowing parameters to maximise the advantage of >92% agglomerates in the burden and in cast house practices to manage the increased slag rate were done.

With the increase in pellet replacing lump C-Ore there is drastic change in furnace specific fines and moisture input to furnace (7 kg/thm and 8 kg/thm respectively). The adjustment in burden distribution furnace gas utilisation improved by 2 points. Furnace productivity improved by 0.25 points, PCI rate improved by 20 kg/thm, fuel rate reduced by 7 kg/thm (after normalising slag rate and other changes in raw materials quality), with improvement in HM Quality Index.

Keywords: Blast furnace, Pellet, Burden distribution, Productivity, Techno economics, Hot metal quality.

BF Stack Shotcrete and Process Improvement at F Blast Furnace Tata Steel

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F blast furnace of Tata steel started on Feb'13 after complete relining. Dense cooling plate arrangement designed by M/s Daniel Corus was introduced. After smooth run of 5 years, we experienced irregular process performances like high permeability resistance (K), excursions in lower stack; which led to high coke rate operation to avoid any major process upset. Utilizing an opportunity in shutdown on Dec'20, burden was lowered down to 14 m to see inner stack profile and condition of cooling plates. It was found that many cooling plates were exposed at mid and lower stack due to refractory erosion. Some scaffolds were also seen at lower stack level. Exposed cooling plates act as anchor to build scaffolding on inner wall. Literature also suggests that scaffolds are responsible for spikes in lower K and irregular gas flow pattern, which is true for F blast furnace also.

After analysing available options, it was decided to go with inner re-profiling with shotcrete due to less rebound loss, which led to less influence on slag and longer life of furnace. On the basis of erosion profile, a team comprising of BF and refractory decided for 40 tons of material to be applied at lower to mid stack. On April'21 as per plan, burden was lowered down to 17 m, decided

shotcrete material consumed for re-profiling, which starts from 17 m of stock level till cross over of cooling plates and staves which were at 8.2 m of stock level.
After shotcrete, improvement in gas flow pattern was seen with stable lower K and no excursion in lower stack, which enabled to reduce coke rates from 355 to 330 kg/thm as monthly average and stable production. Failure frequency of cooling plates also reduced.

Blast Furnace Operation with High LOI (Loss on Ignition) & High SiO_2 Ore @JSW Steel Ltd, Salem Works

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JSW Steel Ltd, Salem is a 1.0 MTPA integrated special alloy steel plant with two mini blast furnaces (BFs) with useful volume of 402 m^3 and 640 m^3. BF produces liquid hot metal from raw materials and supplies it to steel melting shop.
Hot metal production and quality are dependent on raw material quality and stable furnace operation. One of the major parameters affecting the stability of operation is the quality of iron ore.
Hot metal production was around 1850 to 1900 tpd with 145 kg/thm PCI (Pulverized Coal Injection) while using premier grade (High Fe, Low (SiO_2, $Al2O_3$ and LOI)) Iron ore. Due to non-availability of premier grade iron ore, low grade iron ore was used.
While using low grade iron ore, frequent self slips were observed, and hot metal production came down to~1780 tpd with 110 kg/thm PCI. Usage of this low-grade iron ore caused more fines generation inside the furnace which is due to the crack formation during LOI removal at 600-900 ^{0}C. As a result, furnace permeability got affected and it has hindered PCI injection.
Also, due to non-availability of low SiO_2 (3 to 3.5%) iron ore, high SiO_2 (> 8%) iron ore was used. This has created resistance in the furnace and blast acceptance got reduced. This is mainly due to primary slag formation and its impact on cohesive zone. To increase the hot metal production with this low-grade iron ore, tuyere velocity was operated in the optimized level and burden distribution was adjusted based on the furnace operating parameters. Sinter basicity increased from 2.1 to 2.2 and MgO from 1.9 to 2.0% to reduce the fines generation inside the furnace.
Because of these process improvements, hot metal production increased from 1780 to 1900 tpd with 135 kg/thm PCI when using low grade ore up to 70% in BF2.

Keywords: Iron Ore Quality, Self-Slip, Sinter Analysis.

Investigation of Gas Dynamics Processes for Improved Aerodynamics of Large Blast Furnace

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In this paper, considerations regarding the effect of pressure loss in front of tuyeres and the distribution of the burden and gas flow in large blast furnace (BF) are examined with particular reference to operating parameters of BF#5 (Kalyani) at IISCO Steel Plant, Burnpur (ISP). Laboratory investigations were carried out to assess the characteristic raw material qualities determining the gas flow aspects inside the shaft reactor. A formula was established to correlate the top gas temperature with the heat flux ratio of the furnace. Continuous measurement of the stack pressure drops was made under different furnace operating conditions and quantitative investigations were carried out on operating furnace at ISP. A significant transient behavior of the pressure drop was observed especially in lower and middle zones of BF as a function of the accumulation of liquid phase and the progress of smelting process respectively. It has been observed that the rate of burden descent between consecutive casts reflects fairly the accumulation and drainage of the liquid products as a result of which heat transfer, reduction and aerodynamic processes assume transient character. The analysis of gas temperature at the stock-line showed that variations are more pronounced in the central and peripheral regions, whilst in the intermediate regions the conditions are relatively stable. The transient nature of the aerodynamic processes inside the reactor revealed the existence of an appreciable reserve capacity. Elimination of transience was tested on the furnace at ISP and it leads to improved operating parameters. Further study with respect to flooding, fluidization and stave temperature index calculation is being carried out to optimize the gas flow pattern to get better BF gas efficiency measured in terms of η_{CO}.

Strategies Deployed for High Liquid Production in Blast Furnace Units, JSW Steel Ltd

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JSW Steel, Vijayanagar works is equipped with 4 blast furnaces and 2 Corex units for Ironmaking. The input raw material feed to the ironmaking unit are inferior and has specific Al_2O_3 input >75 Kg/thm and slag rate around 400 Kg/thm. Improving productivity in high slag rate, the following strategies are deployed:

- Improvement in tapping duration (Three taphole operation in BF4 and installation of parallel slag granulation facility in BF1).
- Utilisation of low pressure oxygen through blower (Vacuum Pressure Swing Absorption).
- Use of dry quenching coke and coke drying facility from sinter plant waster gas.
- Improved burden distribution.
- Implementation of digital solution.

The improvement helped in achieving global benchmark in terms of total liquid productivity of 0.87 t/m^3 of working volume.

Keywords: Productivity, Technology, High Slag rate, Oxygen enrichment.

Sustaining Production in Single Trough Operation by Adjusting Blowing Parameters and Optimizing Casting Practice

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Conversion of raw materials to rolled products essentially involves four major steps including raw material dressing, hot metal production (Ironmaking), steelmaking (LD shops) and rolling (Rolling mills). Iron making through blast furnace (BF) is one of the primary processing steps wherein reduction of iron oxides in the raw materials into metallic iron occurs through a counter current movement of gases and raw materials. The gases flow in the upward direction while the raw materials move downwards along the furnace shaft. For a blast furnace to produce hot metal in an efficient and stable manner, three major variables play a significant role. These variables are raw material quality, blowing parameters, and the casting practice. The choice of the casting practice determines the flow of liquids in the furnace hearth and their evacuation, which subsequently affects the movement of gases in the furnace. One of the essential parameters while selecting a casting practice is tap-hole length. Different furnaces have different number of tap-holes and troughs depending upon the relative size of the furnaces. In order to maintain the health of the troughs, routine maintenance is required. Hence, for a furnace having only 2 troughs, when one goes for repair, production is generally compromised. At G blast furnace, Tata Steel Jamshedpur, trials were carried out to prevent compromising production by adjusting blowing parameters and modifying the casting practice.

Keywords: Hearth, Single trough operation, Blowing parameters, Casting practice, Liquid level, Blast furnace.

Critical Parameters affecting Blast Furnace Coke Rate

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Heat demand in blast furnace depends primarily on raw material characteristics, blowing parameters and process stability. In this work, data driven approach was applied to identify critical factors affective coke rate. Total stable operating period of 300 days was considered. Nearly 112 variables including monitoring, controllable and input variables were analysed on coke rate as output parameter. Most critical parameters affecting coke rate were slag rate, coke moisture, hot blast temperature, coal injection rate, heat loss, coke CSR, sinter percentage, sinter CaO, alkali load, and hot metal manganese. Correlation coefficient was 0.9. Regular fine tuning and guideline of thermal control parameters is decided based on derived coefficient. The measures to reduce the coke rate in blast furnace are coke moisture reduction and control, slag rate reduction, maximization of sinter and coal rate. Recently, there was increase in hot metal manganese due

higher manganese in ore. As result, coke rate was offshoot by 5 kg/thm. For stable operation and process stability, manganese in hot metal was restricted below 1%.

Optimisation & Stabilisation of Hot Metal Production During Pandemic Period at Blast Furnaces, Vizag Steel- RINL

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Two out of three large capacity blast furnaces were put down at beginning of the pandemic period at Vizag Steel Plant to match with restricted production plan with limited resources. It was decided to shut down BF#2 and BF#3 and to operate BF#1 only. The furnaces were prepared accordingly and shutdown was taken on 25th March and 13th April of 2020 without salamander casting and burden filled up condition. BF#2 and BF#3 were re-commissioned on 27th July and 17th October of 2020 respectively. Hearth of both the furnaces was totally chilled condition and philosophy of revival of chilled hearth furnace was adopted with full preparation with regard to establish hearth connectivity and handle cold metal slag initially. Maximum annual production (2.26 MT) was achieved from blast furnace during the FY 2020-21. Experiences in re-commissioning and stabilization of BF#2 and BF#3 after long shut down were very much helpful.

Keywords: Blast furnace, long shut down, re-commissioning, stabilization.

Productivity Enhancement with Existing Facility in E-Blast Furnace

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E Blast Furnace is one of the smallest and oldest blast furnaces in Tata Steel. It has very limited

and old facilities. The charging system is skip charging arrangement and there is no facility of raw material screening. It is very difficult to operate blast furnace smoothly with unscreened raw material and less agglomerates in burden. Also during tapping, slag is taken in limited number of cinder ladle as slag granulation facility is not available which is also a constraint and due to this several non-dry tapping are being closed. In such adverse conditions, maintaining production rate and blowing parameters is very difficult as permeability resistance of furnace is always a matter of concern. E Blast Furnace has increased its production from 1150 tpd to 1400 tpd with existing system and raw materials with productivity enhancement from 1.75t/m^3/day to 2.2 t/m^3/day. This paper will explain about the actions taken and improvement in various areas to enhance productivity in such a small furnace.

Improvement in Coal Combustibility through Lance Design Modification and Blowing Parameters Adjustments

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Pulverized coal injection is used to reduce the hot metal production cost by partially replacing the expensive metallurgical coke with the non-coking coal. Higher PCI rate causes various process shifts in the blast furnace operation with reduced replacement ratio of coke to coal. With the existing industrial parameters, an increase in coal rate beyond a critical value causes significant dust loss through furnace top. This appeared, primarily, due to reduction in coal combustibility at relatively high injection rate. Drop in combustibility of coal resulted in significant increase in dust loss through furnace top gas. To address the coal combustibility issue at higher coal rates, suitable modifications in lance design were done to reduce coal velocity whilst improving the dispersion of coal. Further to increase the raceway depth, blowing parameters were optimized to increase tuyere velocity. These measures helped in reducing the dust loss and lowering the carbon rate of the furnace.

Keywords: Pulverized coal injection, Blast furnace, Coal combustibility, Coal lance design, Raceway depth, Dispersion.

Stabilization of Blast Furnace-1 Operation at Higher Slag Rate

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Blast Furnace-1 of JSW Steel Dolvi works is Nippon Steel Corporation designed, recently upgraded in the year 2016. Working volume (WV) of this blast furnace is 3524 m^3 and hearth diameter of 13.8 m equipped with four tap-holes. Pulverized coal is injected through 36 tuyeres with special arrangement of co-axial lance for partial addition of cold oxygen. Due to grinding capacity limitation, PCI rate maintained between 160-165 kg/thm. In 2019, BF-1 has achieved maximum productivity of 2.9 t/m^3/d with 375kg/thm slag rate. In 2020, Dolvi works started consuming low and medium grade ore from their own captive mines. It was containing very high alumina upto 3.8-4.2% which led to increase in blast furnace slag rate upto 460 kg/thm. Consequently, fuel rate in blast furnace was increased by 17 kg/thm and hot metal productivity was reduced to 2.7 t/m^3/d. Major impeding parameters for achieving stable operation at higher slag rate was liquid drainage and maintaining good quality sinter. Fourfold actions were taken to counter higher alumina in iron ore fines and elevated slag rate in blast furnace. Firstly, PCI rate was restricted to 150 kg/thm. Secondly, continuous monitoring of liquid level and quick tapping philosophy with overlapping concept allowed to manage quick liquid evacuation. Thirdly, slag chemistry was modified to improve slag fluidity and hot metal temperature target was increased by 10 ^oC. Lastly, sinter chemistry was adjusted to offset higher alumina. All these actions led to achieve consistent hot metal production at higher slag rate.

Keywords: Captive mines, Alumina, Silica, Slag rate, Strategy, Cost and Timely availability.

Dual Lance Injection System and Improvement Journey to Sustain as Indian Bench Mark

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A high rate of pulverized coal injection through the tuyeres ensures higher production and lower hot metal cost. The injected coal acts as an auxiliary fuel and decreases the consumption of coke. In 2008 H Blast Furnace, Tata Steel Jamshedpur, was commissioned with a single lance pulverized coal injection system with the designed capacity of 150 kg/thm. As we progressed on the journey to increase the PCI rate from 150 kg/thm to 200 kg/thm, we found the single lance operation system inadequate for ramping up the injection rate. The options available were either to increase the diameter of the lances being used in single lance operation or use dual lance injection system. It has been established through research that dual lance injection system has a better efficiency. The dual lance system allows the coal particles to have a low velocity in front of the tuyeres without lowering the injection rate. This ensures that the coal particles undergo complete combustion and consequently a better replacement ratio is achieved. The present study considers a dual lance system for injection of pulverized coal. H Blast Furnace uses 68 lances for PCI injection and the poor availability of lances may cause a deterioration in RAFT, leading to operation difficulties. To increase the availability of lances at H Blast Furnace, we have adopted innovative measures like tuyere monitoring system through tuyere cameras, lance availability monitoring and online lance changing facility. This has helped us in increasing the availability of lances and sustaining as the Indian bench mark in PCI.

Keywords: Pulverized Coal Injection, Dual Lance System, Tuyere Monitoring, Lance Availability Monitoring, Online Lance Changing.

Utilization of Lean Grade Iron Ore for Iron Making in Microwave-assisted Carbothermic Reduction

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The feasibility of producing direct reduced iron (DRI) from composite pellets through microwave-assisted carbothermic reduction by utilizing lean grade iron ore has been investigated. The study includes the optimization of the pelletizing parameters to obtain good quality composite pellets, and subsequent reduction process for DRI production. The composite pellets at the optimum conditions could attain the desired specifications of various properties such as, drop number and dry strength. The reduction study of the composite pellets reveals that around 85–90% metallization could be obtained under optimum conditions viz. a microwave power of 1-2 kW, a temperature of 1200 °C, an exposure time of 60 min, and a C/O molar ratio of 1.0. The characterization studies of the reduced composite pellets showed the sequential growth of the metallic phase as the reducing parameters are increased. The proposed route of DRI making by microwave-assisted carbothermic reduction is a promising process as it is faster, energy-efficient, utilizes lean grade ores and requires less amount of reductant than the conventional route of iron making.

Keywords: Iron Ore, Composite Pellet, Microwave, Direct Reduction, Metallization.

Experience of using Low Grade Pellets at the Gas based DRI Plant at JSW Steel Limited

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Generally, there are two established steel making routes; one is the conventional BF/BOF route while the other is (Direct Reduced Iron) DRI/EAF route. Depleting resources of coking coal in the world is posing a threat to the conventional BF/BOF route of iron and steelmaking and recent

developments in DRI/EAF Processes offer scope for better and energy efficient steel production. Various processes of direct reduction (DR) of iron ore to metallic iron are now developed which uses non-coking coal/natural gas to reduce iron in solid state. The DRI is used as raw material for electric arc furnaces (EAFs) to make value-added / specialty grade steels (especially automotive flat rolled, cold heading - rolled and wire). Typical DRI grade pellets used in DR process contain iron in the range of 65-69%.
Vijayanagar works, JSW Steel Limited has two Corex C-2000 modules operating since 1999. With increased demand for quality steel and insufficient supply of coking coals, it was proposed to install one DRI Module. This module was based on Corex export gas to get additional iron by using hot DRI in Electric Arc Furnace for production of quality steel. This will help achieving competitive advantage in dynamic global market for steel. Now, a Midrex technology based shaft furnace having a capacity of 1.2 MTPA DR Pellets using Corex gas is available. It is the second DRI Module in the world which is based on Corex gas and unique with pressure swing adsorption (PSA) technology for CO_2 removal. Iron ore is fed in the form of pellets to the DR unit and Hot DRI (HDRI) is the product.
There is a challenge to process and efficiently use low grade iron ore through pellet making for DRI Production. Accordingly, Vijayanagar works has been working to use low grade iron ore pellets (iron content 60 to 61%) to obtain DRI having metallization 91 to 93% and carbon 1.1-1.2% with acceptable properties such as, cold crushing strength > 240-260 kg/pellet, reduction degradation strength 8 to 10% under 6.3 mm. The study summarizes the experience and impacts of handling low iron content pellets and its impacts on DR process and product quality.

Keywords: Pellet Fe, Low Grade, Metallization, Carbon, Cold Compression strength, Iron Ore, CCS, RDI, Fe.

Insight into MIDREX Furnace

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MIDREX furnace is a counter-current gas-solid moving bed reactor which converts solid iron ore pellets into sponge iron. In the present work, a steady state model of the MIDREX process has been developed based on the governing differential equations representing material and heat balance in solid and gaseous phase. A program has been developed to solve the ordinary differential equations in an iterative method in order to estimate the concentrations and temperature profile of all the species, reproducing the reduction behaviour of the pellets, along the length of

the furnace. The model predicts the variation in the reaction extent and reacting gas composition along the length of the reactive zone as well as the composition of reducing gases on optimum production rates with agreement to real midrex plant.

Low Carbon Blast Furnace Ironmaking, JSW Steel Limited, Vijayanagar works

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JSW Steel is keenly focused on reducing HM cost and increasing HM production with reducing overall carbon emission. Presently all BF are operating producing more 2.85 t/m^3/d (WV) and carbon rate in the range of 430-440 kg/thm at 400 kg/thm slag rate. The paper describes the key strategies adopt for improving techno-economics such as. a) stabilising pulverised coal injection >200 kg/thm with replacement ratio >0.95, b) improving gas utilisation >48 %, c) increasing hot blast temperature >1160 ^{o}C, d) implementation of digital solution and e) improvement in input raw material properties. Currently large blast furnace is operating with fuel rate of 520 kg/thm at 400 kg/thm slag rate. This paper also describes the future strategies to be implemented to achieve the sustainability targets such as natural gas injection, BF gas recycling, Hydrogen injection, carbon capturing and utilisation.

Keywords: Large blast furnace, low fuel rate, lower cost, higher PCI rate.

A Drive towards the Production of Green Steel by Improvement in Hot Blast Temperature

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Modern steel industries are now strongly expected to decrease CO_2 emissions. The blast furnaces (BF) require approximately 500 kg of carbon (coke and pulverized coal) to produce 1 ton of hot

iron, so about 2 ton of CO_2 is emitted. To reduce CO_2 emission from BF, many efforts have been made. The BF is a well-established system and is highly optimized already so there is very little scope exist to reduce carbon consumption ultimately reduce the CO_2 emission. In addition to the BF, other ironmaking sub-processes such as coke ovens, sintering plants and hot stoves are sources of CO_2 emission. Intriguingly, about 1/3rd of CO_2 gas emission in the ironmaking process comes from hot stoves, comparable to that from the BF. Global hot blast stoves delivering temperatures up to 1350 ^{o}C and Indian blast furnaces stoves are up to 1200 ^{o}C. The hot blast system heats the blast air between 1000 and 1300 °C. It is known that coke consumption will be decreased by 10–15 kg per ton of pig iron with increase of hot blast temperature of 100 K. Hot Blast Temperature (HBT) provides the cheapest thermal energy for blast furnace. BF energy consumption and CO_2 emission will be reduced by increasing the hot blast temperature. The maximum temperature of hot blast, however, will be restricted by the cost of injected fuel and high temperature properties of refractories.
The major developments involve improving reliability of stove instruments, reducing breakdowns in stove valve, developing process parameter optimization model during 2 stove operation, shifting from sequence operation to hybrid operation, heating and cooling cycle time optimisation, stove heat balance model development, stove design, blow pipe refractory design, etc. This paper discusses the various methods for increasing HBT to reduce the coke rate and drive towards production of green steel.

Keywords: Hot blast Temperature, Reduction in CO_2 emission, Reduction in Fuel consumption, Green steel.

Chromium Partitioning Studies on Production of Low Carbon Ferrochrome Alloy from Sukinda Chromite Ore Fines

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Low carbon ferro-chrome is mainly used in producing different grades of alloy steels as it provides corrosion and oxidation resistance, improve wear resistance at elevated working temperature. India produced 3.97 MT chromite ore during the calendar year 2020. More than 99% of chromite ore was mined from Sukinda valley in the state of Odisha. Sukinda chromite ore is friable in nature and hence, more than 90 % of mined ore is generated as fine material (less than 10 mm). Chromite

fines can be smelted in electric arc furnace, but high proportion of fines in the burden will lead to operational difficulties, resulting in poor furnace performance. Thus, chromite fine agglomeration is an effective measure to reduce production cost.

In the present study, equilibrium calculations were made using reaction enthalpy and thermodynamic software FactSage 6.4 (Equilib module) for chromite ore smelting (Cr_2O_3-Fe_2O_3-SiO_2-CaO-MgO-Al_2O_3). The study helped to understand the effect of addition of reductant and fluxes to produce low carbon ferro-chrome with higher chromium recovery. At first, pre-oxidation of chromite ore was done to breakdown the spinel structure for better reducibility and higher chromium recovery. Pre-oxidized chromite fines and required amount of fluxes was agglomerated to make 10-15 mm diameter balls. Experiments were carried out in the 50 kVA electric arc furnace on a 20 kg scale to assess the effect of some parameters viz. tapping temperature, specific power consumption and chromium recovery. It was observed that with optimum addition of ferro-chrome-silicon and adjusting the slag composition, low carbon-ferrochrome was produced with a slag having melting point of approximately 1656 ^{0}C. Measured slag was sufficiently fluid at the tapping temperature of approximately 1789 °C. Ferro-chrome-silicon addition decreases the liquidus temperature of slag due to exothermic energy released from the silicothermic reduction process. The low carbon ferro-chrome produced by this process showed high metallic yield of 85% with a chromium recovery of 91%. The alloy composition consisted of 65% Cr, 37% Fe, 0.12% C, 1% Si and the final slag had very low Cr and Fe (0.76% Cr_2O_3, 0.98% FeO).

Optimization of the Chute Angle for Centre Coke Discharge in Blast Furnace using DEM Simulations

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Blast furnace operators want to concentrate gas flow through the blast furnace centre so that the walls can be protected from degradation due to heat losses, along with improvements in pressure drop and other parameters. In view of this, the practice of charging larger sized coke particles, also known as centre coke, has been adopted in blast furnaces worldwide. In this study, we have

developed a methodological approach towards determining the optimum chute angle which should be set for centre coke discharge in the blast furnace. We have used discrete element method (DEM) simulations to determine the effect of chute geometry and inclination angle on the subsequent formation of the centre coke heap. First, we have characterized the actual centre coke material using physical experiments like angle of repose. Using the experimental data, we have prepared a replica DEM model of the centre coke that mimics the actual centre coke material and then use it in simulations. Using the 3D CAD of actual chute geometries, simulations of heap formation have been performed. It has been found out that chute geometry profoundly affects the material trajectory in the furnace, with high scatter of flowing material obtained at low chute angles and vice-versa. But at high chute angles, the heaps formed were found out to be flatter and wider. Effect of these on the heap formation have been studied and an optimum angle has been suggested for operations. Blast furnaces have implemented the suggested chute angles and found improvement in operational parameters like central working index (CWI) and bed permeability, which have enabled smoother operations.

Numerical Investigation of the Effect of Raceway Shape and Size on Gas and Fines Flow Behaviour in a Packed Bed with Cohesive Zones

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Two-phase (gas-powder) flows are ubiquitous in metallurgical, chemical and petroleum engineering such as blast furnaces, reduction shaft, catalytic reformer, etc. despite which, a comprehensive understanding of the fundamental process is lacking. Modern techniques such as pulverised coal injection in iron-making blast furnace further increase the complexity of the process. While increasing the coal injection rate leads to the economic and environmental benefits, an unrestricted injection increases the amount of unburnt coal and coal ash inside the blast furnace, which will ultimately reduce the internal permeability and adversely affect the operational life of the furnace. The criticality of understanding the process along with the difficulty in an experimental study have incentivized theoretical studies which employ appropriate mathematical models and empirical correlations.

The present work incorporates these features into a 2D numerical study of a gas-fines-solid system with validation through experimental studies. The mathematical modelling considers the gas and fines as an Eulerian-Eulerian system with the constant voidage model for the solid phase representing the packing particles and well established theoretical relations for inter-phase forces and raceway modelling.

The effect of raceway shape and size on the overall fluid dynamics (heat and mass transfer) and fines holdups as the tuyere protrusion, gas inlet velocity, packing particle material, packing particle size, fines flux through the tuyere opening, and fines size are varied is simulated and analysed in depth. The flow and accumulation characteristics for other aspects, such as the presence and configuration of the cohesive zones, are also considered and presented. The results indicate a robust mathematical model which demonstrates very good predictive capabilities of the raceway and fines accumulation characteristics.

Keywords: raceway, fines flow, packed bed, blast furnace, cohesive zones, transport processes.

Three-reactor Approach to Basic Oxygen Steel Making Process using FactSage and its Macro Facility

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The refining process in steel making involves multiple reactions occurring simultaneously in a short span of 15-20 minutes, which limits detailed understanding of the process behavior. Hence, we developed a dynamic model to predict the behavior of the process in terms of transient composition, temperature and volumes of liquid steel, slag and top gases involving multi-reactor model based upon thermodynamics of chemical reactions and their mass/heat transfer governed kinetic limitations. In this work we have used four reactors to described the overall basic oxygen steel making process namely two are non-equilibrium chambers and two adiabatic reactor which are interconnected with each other. We used the macro programming facility of FactSage™ software to understand the thermochemical model of basic oxygen steel making process. The model predicts the bath as well as reactors composition and temperature for every minute of blowing time. This model reveals dry slag formation periods of operation.

Keywords: Steelmaking, basic oxygen furnace (BOF), decarburization, Factsage, macro program, modelling.

Numerical Modelling of Thermal Behaviour in a Step Mould Ingot Casting Process

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The global competitive market for production of advanced high strength steel grades catering to the needs of the customer creates driving force to understand the linkage between the as-cast solidification structure and cooling rate for new alloy development. Laboratory scale casting trials in an in-house developed step mould can be a cost-effective way to simulate thermal conditions in single casting trial comparable to that during a continuous casting process. The designed mould consists of steps of varying thickness thereby simulating different thermal behaviours across different steps of the cast section comparable to that observed in continuously cast slabs. Computational models are effective tools for fundamental understanding of the intricate physics of the casting process and thereby provide useful insights to enable quality improvement. Hence a thermal model for the mould has been developed to understand the heat transfer behavior at different steps of the mould. A finite volume based ingot solidification model has been developed to track the solidifying shell after incorporating appropriate boundary conditions. The model has been validated for benchmark literature cases of isothermal phase change problem as well as two phase solidification problem. In the end, 2D transient simulation in the step mould has been performed to numerically simulate the temperature evolution across the different steps. Later the cooling rates across different steps based on the numerical model will be correlated with the dendrite arm spacings measurements of the cast ingot. The thermal model considers heat transfer by radiation at pouring temperatures, mixed mode of heat transfer at the interface of the mould and the shell and the natural air cooling at the mould surface.

Keywords: Step mould, solidification structure, continuous casting, solidification model, air gap.

Numerical Investigations into Flow Pattern, Solidification and Slag Behavior in Continuous Casting Slab Casting

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In continuous casting, the flow pattern of the incoming liquid metal stream from submerged entry nozzle(SEN) is important in determining the velocity field, inclusion transport and steel-slag interface fluctuation in mold. High impurity in the form of inclusions can lead to rejection of the final product. The behavior of the interface and meniscus is mainly affected by the upper roll pattern. The lower roll pattern influences superheat transfer and solidification thickness. Therefore, in this study, a coupled model of liquid steel flow, heat transfer, solidification and steel-slag interface is developed. Enthalpy porosity technique is used for solidification and interface modeling is performed using the volume of fluid(VOF) method. Different flow field and heat transfer parameters are analyzed in the mold and at the interface to understand the flow dynamics.

Development of a Thermal Model for Continuous Casting Process using OpenFOAM

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Continuous casting process is a primary manufacturing process that includes physical processes such as heat transfer, fluid flow, solidification and solute transfer. Several parameters are to be optimized in order to obtain superior product quality which will meet the customer requirements. Particularly, the process conditions that control defect deformation are to be determined with the help of physically based criteria. In the past, process modelling considered the casting from the tundish region to the end of the continuous cast product using commercial software. However, the use of open source software to create a digital twin of this process has not been completed.

OpenFOAM is an open source C++ based library that can be used to model the continuous casting process. OpenFOAM provides the advantage of configuring customized solutions by extending the numerous in-built solvers as well as creation of new solvers to capture the physical processes. Thermal analysis of the continuous caster has been taken up for this study and the heat transfer coefficient is optimized for a stable steady state process. The probe data from this model can be used as a dataset for defect prediction purposes. A digital twin of the continuous casting process can be developed in a modular fashion. This study aims to provide one such module that could be calibrated with industrial data for useful application.

Oxygen Prediction Model in Energy Optimizing Furnace (EOF)

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Energy Optimizing Furnace (EOF) is a type of basic oxygen furnace which is used in primary steel making. The input charge mix for EOF is 80 to 85% of hot metal, which is an output from the blast furnace and 15 to 20% of scrap. Major role of EOF is the conversion of hot metal and scrap into liquid steel by blowing oxygen through bottom tuyeres. The process involved during blowing in EOF is decarburization and dephosporization. During blowing, the residual oxygen gets entrapped inside the steel bath owing to its higher solubility at steel making temperatures. The oxygen level is measured using Celox instrument. Variation in residual oxygen level affects the consumption of alloys in Secondary steel making and impacts the quality of the final product. In order to reduce the variation, it is imperative to develop a dynamic oxygen prediction model that is capable of providing the actual level of oxygen in steel. Data were collected for actual oxygen levels and various factors affecting the residual oxygen level. Statistical Equation was derived through regression analysis to predict the O_2 level. Model data were validated with the Celox measurements. Through this model, oxygen level in liquid steel can be calculated without the help of Celox instrument. The model helps reduce the variation of residual oxygen in liquid steel, controls the alloys consumption in the secondary steel making process and improves the quality of the final product.

Double Slag Practice in Induction Furnace Steelmaking

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The secondary steel sectors contribute more than 55% to total steel production in India. Steelmaking through the induction furnace route is approximately 30% of the total steel production in India. The average phosphorus content in the steel, produced through the induction furnace route using DRI, is in the range of 0.085 to 0.1% while sulphur is around 0.06-0.1%. According to BIS standard, the phosphorus and sulphur content in any structural steel varies between 0.03 -0.06%. However, the induction furnace steelmaking route has its own limitations for the refining of liquid metal to produce low phosphorus and low sulphur steel. The presence of high phosphorus in the engineering steel component causes cold shortness, i.e. the phosphorus increases the DBTT, whereas sulphur affects the hot shortness. Therefore, CSIR- NML has developed the flux for dephosphorisation and desulphurisation of steel in the induction furnace. It has been found that phosphorus content in steel is reduced to 0.025 % with the addition of a developed flux of 2-3 wt. % of the liquid steel. The desulphurisation time to achieve the sulphur level (0.03-0.04) is 10 minutes in the induction furnace using developed synthetic slag. Hence, developed flux is suitable for double slag practice in induction furnace steelmaking.

Keywords: Dephosphurization, Desulphurisation, Synthetic slag, Induction furnace, Steelmaking.

Effect of B_2O_3 as Fluxing Material on Steel and Slag Properties in Ladle Furnace Refining

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In BOF during tapping and LF (Ladle Furnace) treatment, 700-1200 kg of $CaO-Al_2O_3$ based synthetic slag along with 300-500 kg lime per heat is being used as slag conditioner in Si-killed steels. Addition of synthetic slag helps in desulphurization and improves steel cleanliness. In present study, boric acid (H_3BO_3) along with lime is used as an alternative fluxing material to partially substitute synthetic slag for treating Si-killed steels.
The main objective of this research work is to optimize lime and boric acid additions to partially replace synthetic slag without affecting the process parameters. B_2O_3 will combine with other oxides such as CaO, MgO and forms low melting point eutectics, which decreases the melting point and viscosity of slag. This helps in improving slag fluidity even in the higher basicity range of slag and enhances the desulphurization kinetics. LF slag however, disintegrates into fine powder during cooling due to phase transformation of β-C_2S to γ-C_2S. B_2O_3 sources stabilize high-temperature polymorphs of pure C_2S by forming solid solution, and prevent disintegration of LF slag.
Industrial trials were carried out by varying boric acid and lime additions. From the results, it was observed that desulphurization efficiency improved with B_2O_3 additions. The slag melting temperature was measured with ash fusion temperature equipment; it is below 1400 °C. Usage of B_2O_3 as alternative fluxing material helped in reducing synthetic slag consumption to 100-500 kg per heat in silicon killed steels by addition of 60-120 kg H_3BO_3 and 700-1000 kg lime. Addition of H_3BO_3 and lime were optimized based on industrial trials. In the present study, B_2O_3 additions also helped in preventing disintegration of LF slag and lump slag was generated after cooling. This also helped in improving valorization potential of LF slag.

Keywords: Ladle Furnace, Desulphurisation, fluxing agent, LF slag, Boric acid, Synthetic slag

Reduction of Aluminium and Lime Consumption by Suitable Selection of Alternate Deoxidizing Compound

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Aluminium (Al) is one of the most important input raw materials for steelmaking process. Aluminium is used as a deoxidizer in steel making process to deoxidize the dissolved oxygen ppm. Though aluminium is an effective deoxidizer, it is very costly for which an alternate cost-effective deoxidizer is required. The price and availability of raw materials has always been a decisive factor in steel making plants for which steelmakers are searching for cost effective alternate solutions for all the additives. Since deoxidation is a key steel refining process affecting steel cleanliness, hence proper chemistry selection of the alternate deoxidizer is required. An alternate deoxidizer compound having metallic Al content in it along with lime (CaO) and alumina (Al_2O_3) based compounds was chosen for the purpose. The metallic aluminium present in it will take care of the steel deoxidation during addition and the oxide compounds will help in effective slag making. The current paper detail the trials that were conducted using an alternate deoxidizer to deoxidize the tapping stream and comparison was done with existing practise of Al killed steel grades. Samples were taken after steel deoxidation at online purging station (OLP) to check the oxygen potential level (ppm) after deoxidation of steel. The slag behaviour at Ladle Furnace (LF) along with steel desulphurization using alternate deoxidizing compound was studied which is an indication of steel cleanliness level. This paper summarises the work done for reducing the overall consumption of Al at steel making by choosing an alternate deoxidizer which helped us to reduce ferro alloy cost without impacting steel quality.

Keywords: Al-killed Steel, Tapping, Deoxidation, Ladle Furnace, Alternate Deoxidizer.

A Curious Case of Carbon Pick-up in Electrical Steel

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Carbon content in electrical steel is very critical as it affects the core loss/watt loss of the steel after ageing. At JSW Steel, electrical steel is manufactured through RH route with controlled decarburization under vacuum. However, the carbon content in steel, particularly in sequence 1st heat, gets increased due to pick-up in subsequent downstream processes. The pick-up was evident in two stages, viz from RH to tundish and from tundish to slab. The average pick-up from RH to slab is measured to be ~ 13 ppm with highest pick-up up to 27 ppm and thus has been a cause of a big concern. High Carbon pickup, often leads to increase in core loss and hence heat downgrading. The present study focuses on a systematic approach to identify the factors leading to carbon pick-

up and optimize the process to reduce the pick-up in the steel. This has resulted in reduction in grade diversion from 3.3% in FY18 to 0.92% in FY21.

Improvement in RH Input Conditions to Enhance the Steel Quality for Automotive Industry

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Tata Steel produces a sizeable quantity of interstitial free (IF) steel for auto application which needs to meet stringent surface quality requirement. Such demand for high quality of steel has made the steel producers realize the need to meet product cleanliness requirement. One of the prime concerns of steel cleanliness is the alumina which is generated during the heat making process at RH degasser. At Tata Steel Jamshedpur works, the shop logistics demands aluminothermic heating for any requirement of temperature increment at RH degasser, which in turn, corresponds to high alumina generation which hampers the steel cleanliness at the downstream end. The mapping of microstructural analysis was done with the process parameters of RH degasser, the results of which clearly indicated a direct correlation of the sliver generation with the aluminium consumption at RH.

For understanding the reasons behind the deviations observed in the input condition at RH (RH in temperature/oxygen/carbon), a detailed analysis using various statistical tools was done of not only all the technical parameters, but also the parameters related to shop logistics. The complete cycle time study was carried out right from steel tapping at BOF to the placement of ladle on the turret at caster.

Study of the cycle time of entire process along with the process parameters, revealed that although the aim temperature was achieved at stations like BOF and OLP, but the target input temperature was not achieved at RH degasser. The reason behind this was found to be the improper sequencing of the heats. Detailed analysis on the improper sequencing of heats along with implemented solutions is discussed further in this paper. The improvement done in the above-mentioned parameters have resulted in quality enhancement in steel for automotive applications which is discussed further in detail.

Study of Effect of Calcium Treatment on Non-Metallic Inclusions in Si-Mn Killed Steel Grade

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The demand for producing clean steel grades is increasing to avoid undesirable non-metallic inclusions which can lead to various deleterious effects on liquid steel processing and properties of steel. Inclusion formation is an integral part of steelmaking process and it cannot be wholly bypassed. Amount of inclusion existing in steel, their composition, size, shape and distribution decide properties of steel. Also, liquid inclusion formation after secondary steelmaking at ladle furnace is recognized as a precondition for the steady flow of liquid metal through the small diameter nozzles of the continuous caster. In this regard, calcium treatment is a popular technique to convert oxide and sulphide inclusions in steel to less harmful inclusions. However, either excessive or inadequate amount of calcium addition is disadvantageous as it can lead to formation solid calcium aluminate, calcium sulphide and other unfavourable inclusions thereby hampering the steelmaking process and deteriorating the quality of the steel.

This present work deals with the effect of calcium treatment on non-metallic inclusions in Si-Mn killed steel grade. Steel lollipop samples having different final sulphur level were collected at ladle furnace using a plain sampler. After that, these samples were analysed by automated inclusion analysis software to measure inclusion composition, size, shape and other characteristics. Average inclusion size for all the steel samples varies between 2-3 µm. Automated inclusion analysis of all the steel samples indicate that inclusion density increases after calcium treatment process. However, average inclusion size, average inclusion area, width and equivalent circle diameter decrease after calcium treatment process. Lower calcium (0.027 kg/TLS) addition has been found to be beneficial to restrict the formation of solid calcium aluminate and calcium alumino-silicate inclusions and form more of liquid inclusions compared to the instance of higher calcium addition (0.036 Kg/TLS) condition.

Keywords: Steelmaking, Ladle Furnace, Inclusion, Calcium Treatment, Automated Inclusion Analysis.

Experiences with Pure Calcium Treatment of Steel at IISCO Steel Plant

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The practice of Ca treatment in liquid steel is an inextricable part to make Aluminium killed steel grades for inclusion modification. A range of calcium alloys, like calcium silicide (CaSi), ferro-calcium (CaFe), pure calcium metal based powder etc., are used for this purpose. The conventional methods of Ca treatment are in the form of CaSi and CaFe cored wire. However, of late, the practice of adding pure Ca in the form of calcium cored wire with more than 99% purity is gaining ground across different steel plants because of its superior performance vis-a-vis CaSi and CaFe. Superior performance entails better recovery of Ca and better castability of liquid steel.
Currently, at ISP, CaSi / CaFe cored wire is fed predominantly in Aluminium killed as well as low carbon grades. The percentage of Ca recovery is a popular yardstick to gauge the performance of these wires. At present, the calcium recovery % at tundish is low at ISP, which lies mostly in the range of 2-6 % (determined based on tundish analysis). To tap the benefits of pure calcium addition, Steel Melting Shop, ISP has decided to go for trials of pure Calcium cored wire. In view of this, the present paper aims at assessing the techno-economic implications of adding pure Ca cored wire compared to that of CaSi / CaFe wire.

Effect of Shroud Geometry on Melt Residence in Steelmaking Tundish System

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Flow of molten steel through a shroud, with or without argon injection, can influences flow in

tundish and therefore, exert considerable influence on the metallurgical performance of steelmaking tundish system. In continuous slab casting, throughput rates are generally large, associated intensity of flow in shroud appreciable and these in turn intensifies flow in tundish promoting refractory wear, slag entrainment, large tundish eye and so on which are known to seriously impair steel cleanliness. It is well known that as far as inclusion floatation and removal in tundish are concerned, plug flow is desired, and is generally ensured by a slowly moving, rather than a highly turbulent melt. Thus, to slow down incoming flow from shroud and dampen turbulence in tundish, various measures have been advocated by researchers. Insertion of flow modifiers and pouring box, injection of argon in shroud have all been shown to promote plug flow enhancing metallurgical performance of steelmaking tundish system. In addition to such, modified shroud designs have also been advocated to produce a more dissipative and sluggish flow in tundish in order to fulfil the desired objective. In such context, numerous designs of shrouds have been proposed and their influence on hydrodynamic performance of tundish reported in literature. In the present work, a numerical investigation has been carried out to investigate the influence of two different designs of ladle shrouds namely, the conventional ladle shroud (CLS) and the bell-shaped ladle shroud (BLS) systems on the hydrodynamic performance of a slab casting tundish system, fitted with a turbo-stop and a near strand dam. To this end, a steady state homogeneous turbulent flow model has been developed embodying the standard coefficient, $k-\varepsilon$ model. Numerical simulations were performed via commercial CFD (computational fluid dynamics) package ANSYS FLUENT. It is shown that axial velocity at the outlet of BLS, relative to CLS, is significantly reduced under similar operating conditions. As a consequence, smaller volume averaged velocity and turbulent kinetic energy (TKE) resulted in the system. Associated residence time distribution (RTD), as one would expect, indicates markedly increased mean residence time of liquid coupled with proportionately higher dispersed plug flow volume suggesting essentially that delivery of metal through a BLS in a slab casting shroud (operated with a turbo-stop) can be beneficial and facilitate inclusion removal from tundish improving cleanliness of steel.
The present work was carried out in the absence of any inert gas injection in ladle shroud. Also, the tundish was assumed to be slag free. To make computational results more relevant to actual practice, such features (with inert gas injection) are being incorporated in the mathematical model currently. These will be addressed in a future communication as a full manuscript.

Keywords: Hydrodynamic behavior of tundish, Bell shape shroud, Steel cleanliness, Residence time Distribution (RTD).

Reduction in SEN Change Failure at the Thick Slab Caster

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In the continuous-casting process, control of steel flow is the most effective way to ensure caster continuity and quality optimization. At TATA Steel, SEN change is used as a lever to achieve this harmony between maximum production and stringent quality requirements. However, there are cases where the caster stops due to failure during SEN change wherein machine revival can take between two-three hours which is greatly detrimental to production. The present work was done to understand the different reasons for failure during SEN change and identify and employ innovative solutions to prevent their recurrence. All these cases were then thoroughly deliberated on and categorized into broad headings under which targeted work was done to overcome them. The impact of argon flow on proper stopper closing was analyzed to tackle the phenomenon of steel clogging during casting. Apart from this mechanical equipment reliability was studied to reduce the amount of man-machine interface involved in the process to increase safety and smoothness of operation. Further, the effect of the present human intervention has also been discussed in the following work to identify patterns in failure cases that were repetitive in nature and resolutions for the same were devised and implemented.

Keywords: SEN, Slab Caster.

Understanding in SEN Clogging during Casting of Stainless Steel

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Achieving cleanliness during steel making is a big challenge with conventional steel making process. Inclusions arise as a combination of various processes in steel making. During the continuous casting of steel, non-metallic inclusions might get deposited on SEN wall, leading to clogging, which degrades the cleanliness of the steel and also hampers the casting of the steel. The present study discusses about the clogging phenomenon of the SEN during the continuous casting of aluminium killed stainless steels one containing titanium and the other containing cerium. Characterization using metallography, SEM/EDS and XRD revealed the deposition of spinel based inclusions of type MgO-Al_2O_3-TiO_2 adhered to the SEN wall in the Ti containing grade where as MgO-AL_2O_3-Ce_xO_y type spinels were observed in the cerium containing grade. In order to avoid the clogging tendency, higher silica-based SEN and high bore size of the SEN has been used which decreased the clogging tendency of the grades.

Keywords: SEN clogging, Stainless Steel, Continuous Casting.

Mold Flux Design Criteria for Continuous Casting of High Aluminium Steels

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Mold flux powders used in continuous casting process have some specific role to improve the efficacy. Some of the primary functions of mold fluxes are to i) provide ample lubrication between solidifying shell and mold walls, ii) prevent atmospheric oxidation of molten steel, iii) facilitate optimum horizontal heat flux, iv) and act as a pool for absorption of NMIs. During continuous casting of high Al steels (>0.5% Al) using CaO-SiO_2 based mold powders, the reduction of molten oxides (especially SiO_2) by Al content in steel at the slag-metal interface, has proven to be source of major process irregularities. To overcome the chemical instability of conventional CaO-SiO_2 based mold powders, CaO-Al_2O_3 based mold powders are identified as an alternate for high Al steels. However, it is inferred from many studies and plant reports, CaO-Al_2O_3 based mold fluxes still suffer from lack of continuous lubrication due to irregular crystallization behaviour. Therefore, a detailed investigation to understand the high temperature physic-chemical stability of mold fluxes is essential during the flux design. In the present study, temperature vs. viscosity, solidification and slag-steel interfacial reaction simulations were carried out in thermodynamic software package FactSage 8.1. Upon comparison of results with previously available literature data a composition-property relationship was established for CaO-Al_2O_3 mold fluxes. The influence of individual additive oxides on characteristic temperatures, melting and crystallization behaviour were determined. The understanding developed from present study would be employed further experimental work to design a suitable mould flux for alloys like AHSS etc.

Keywords: Mold Flux, Continuous Casting, Physical Modelling, High Aluminium Steel.

Elimination of Ovality Defect in 200 Round Section by Optimizing the Casting Parameters

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Ovality defect in the 200 round section continuous cast products is caused due to the effect of thermal and mechanical strains and it is the difference between maximum and minimum dimensions of the outer diameter of round blooms. This higher difference is detrimental to the subsequent extrusion process of pipes and tubes. This defect can be seen majorly in the low carbon steel grades and it is visible as discontinuous depressions on the bloom surface. The secondary cooling spray pattern shows intense cooling at the surface exposed to the nozzle and reduced cooling in the adjacent surfaces. This difference in cooling causes the drastic difference in heat transfer between the bloom surfaces. By estimating the nozzle orientation and optimizing the flow pattern of the air-mist, uniform cooling of the blooms can be achieved. Selection of suitable fast melting casting powder is also found effective in controlling the Ovality. In addition to that providing guide rolls makes the bloom remains at the centre line of air-mist spray during continuous casting resulted in improved uniform cooling.

Keywords: Ovality, low carbon steels, nozzle, secondary cooling, casting powder.

Failure Analysis of Continuous Cast Slab through Internal Quality Assessments and Measures for Quality Improvement

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Special quality steel product requires defect free surface finish and complete internal soundness of the final product. Any material vulnerability in terms of defects whether surface or sub-surface can lead to material failure during subsequent processing or service life. Surface defect can be removed

to a certain extent by inspection and surface conditioning but in case of internal defects like transverse or midway cracks which are not detectable immediately can lead to catastrophic failure of material when subjected to further processing. Several factors dictate the genesis of crack and sometimes it can be very difficult to assess the slab quality only by surface finish.
The current work was carried out to assess the internal quality of cast product and mapping of defects to determine the critical parameters responsible for initiation and propagation of crack. Macro-etching of cast slab pieces across the width has been carried out to reveal the defects. Macro and micro metallographic investigation, thermo-mechanical simulation, thermodynamic investigation of the micro-alloying element precipitation behavior etc. has been studied to characterize the defect and material vulnerability. Heat transfer modeling of primary and secondary cooling to find the effect of spray cooling on surface reheating in cooling transition zone has also been studied. Based on the finding a modified approach in spray cooling strategy, machine alignment checking, chemistry optimization and slab handling strategy has been suggested. The new approach has been found beneficial to mitigate the slab failure during subsequent processing.

Keywords: Slab internal quality, Internal Transverse crack.

Controlling of Hydrogen Crack in Rolled Product of Cr-Mo-Ni Steels

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Study on hydrogen cracking assisted with measured diffusible hydrogen content in a typical Cr-Mo-Ni steel has revealed that hydrogen content beyond the critical range is detrimental both at the cast product stage as well as in the rolled product stage due to generation of centre cracks. Estimation of hydrogen content from the cast and rolled product has revealed a decreasing hydrogen gradient from surface to core. The cause of high hydrogen at core is attributed towards transformation of high hydrogen soluble austenite phase with lower hydrogen ferrite phase at surface. The hydrogen evolution in steels with temperature accompanied by the simultaneous dimensional changes due to phase transformation is responsible for the generation of internal cracks called “Flakes”. To decrease the hydrogen gradient from surface to core in the cast product, various process modifications both at steel making and bloom cooling methods were implemented and found to be effective. Hydrogen content pickup in liquid steel due to ferro-alloy additions at

LF and moisture in tundish furniture's were reduced through modified degassing and tundish preparation practice. In addition, further decrease of hydrogen gradient in solidified cast blooms requires isothermal treatment of blooms which is ensured by slower heat dissipation from blooms by modified bloom cooling method.

Keywords: Hydrogen assisted cracking, Anti-flaking, hydrogen gradient, modified practice.

Reduction of Longitudinal Cracks at Thin Slab Caster

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In thin slab casting, longitudinal cracks are serious quality problem. The cold rolling customers of JSW, Dolvi were facing major issue of longitudinal surface crack in coil. Metallographic analysis was made on the defect sample and microscopy morphology; EDS analysis was made by scanning electron microscope. Finally, it is determined that such cracks are originated from the uneven solidification front of meniscus in the mold. This defect become chronic at caster, as sometimes if the crack intensity becomes severe then it would lead to breakout (unplanned termination casting)

The present study investigates the longitudinal cracks defects and analyses the various process parameters right from chemical composition of liquid metal, LRF process parameters and caster process parameters to determine the correlation with defect. The control measures have been taken at continuous casting process including optimization of the primary cooling, reduction of heat extraction at meniscus region by choosing right mold flux, and reduction of the liquid metal turbulence with calmer meniscus by optimizing EMBr current and SEN settings.

The results of industrial test shown that longitudinal crack index was decreased from 9% to 2% by implementation of above measures.

Keywords: Electromagnetic Break, Submerged entry nozzle, Ladle refining furnace.

Investigations on Intercolumnar Cracking in High Carbon Steel Slab During Continuous Casting

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Intercolumnar cracking (ICC) in high carbon and micro alloyed steel grades during continuous casting is a major challenge for steel processing industry. In the current work, investigations on cracking in high carbon steel used for chain link application is being investigated. Metallographic investigations reveal presence of segregation MnS stringers at off centre locations which lead to cracking. The analysis showed the intercolumnar crack generated in slab during continuous casting that resulted in off centre segregation post hot rolling. Current research focuses on analysing the effect of steel chemistry and casting parameters such as casting speed, roll alignment, secondary cooling etc. on the intercolumnar cracking susceptibility of high carbon grades. It is observed that the reduction in deviation in roll alignment among caster segments, low and stable casting speed and modification in secondary cooling pattern for high carbon and micro alloyed steel resulted in decrease in intercolumnar cracking susceptibility. Furthermore, metallographic investigation after implementation above practices confirmed reduction in intercolumnar crack in steel slab after modified casting parameters in a continuous caster.

Keywords: Continuous casting, Intercolumnar cracking, Off centre segregation.

Inclusion Characterization of Free Cutting Steel with Different Heavy Elements

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Free cutting steel grades are high sulphur grades used for manufacturing components like nuts, bolts, studs, hydraulic fittings and brake pistons where higher machining is required to get intricate shape. Quality of these steels is assessed by hardness of the steel, MnS inclusion size and its aspect ratio. In the current work heavy elements namely lead, tellurium and bismuth were added to

conventional EN1A steel grade. Pb, Te and Bi get associated with MnS inclusions due to their low melting point. The distribution of these elements and their association with MnS inclusions was analyzed with Scanning Electron Microscope. Compared to lead, addition of tellurium and bismuth beneficiated in achieving MnS inclusions with aspect ratio 1:6. In addition to the aspect ratio, the chip formation morphology during machining operation was analyzed. Short chip formation is preferred by machining customers. The effect of chip formation behavior is strongly influenced by the aspect ratio and hardness of the steel grade.

Keywords: Heavy elements, MnS inclusions, Aspect ratio, Chip formation.

POSTER PRESENTATIONS

Real time Cold Crushing Strength (CCS) Measurement of Pellets

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Pellet charging has gained importance in blast furnace operation as a promising charge mix to enhance the smelting process and to lower fuel consumption. Pellet helps in achieving uniform bed permeability as compared to iron ore or sinter and therefore, leads to better gas-solid contact resulting in higher productivity at reduced coke and fuel rate. Thus, maintaining consistency in pellet quality is very important to achieve good reducibility and productivity at blast furnace. The quality of pellets is generally measured in terms of cold crushing strength (CCS). Pellets having CCS greater than 200kg/P is acceptable for blast furnace usage and in case of low value, the production is reduced to increase the CCS value. As per IS 8625:1986, the production can be restored only after two consecutive CCS's value has been more than the threshold value. To measure CCS, pellet sample is collected manually from the conveyor, transported to the central laboratory, screened to standard size (diameter 10 to 12.5 mm) and then placed manually on a pneumatically operated machine. The average value of 60 samples is recorded as final CCS and the whole process takes around 2 hours. In case of low CCS, operation team has to wait for next two consecutive high CCS readings i,e a total of four hours with reduced production.

This paper describes an autonomous machine commissioned in Tata Steel, Jamshedpur which automatically picks up pellet sample, screens the pellet to a desired size, crushes the screened pellets one by one and measures the CCS value on real time basis. This eliminates the high waiting time required in case of traditional lab testing method and helps operation team to manage reduced production more efficiently in the event of low CCS.

Maximization of Manganese Ore at Sinter Plants

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JSW Steel Dolvi Works operates their two sintering strands (198 m^2 and 224 m^2) with 100% low grade Odisha fines. One of the major challenges of producing sinter from Odisha fines is higher alumina (4 to 4.5%) and high level of silica fluctuation (3.0 to 6.0%). Due to high alumina in sinter ~ 3.8%, alumina load in blast furnace goes up (80 kg/thm) resulting in increased slag rate up to 470 kg/thm. To counter higher slag rate, iron ore containing higher MnO (7-8%) and lower alumina (2-2.5%) was introduced in sinter feed mix. Mn-ore in sinter feed mix was maximised at 20%. As a result, alumina content in sinter was reduced from 3.8 to 3.5% and MnO percentage was increased from 0.3 to 1.2% in product sinter. This led to reduction in blast furnace slag rate and coke rate upto 24 and 4 kg/thm, respectively. With the increase in Mn-ore fines, drop in sinter cold strength was observed. However, the same was managed by sinter productivity. Manganese in hot metal increased up to 0.8%. Because of this, sulphur in hot metal was reduced by 10% but convertor lining life was reduced due to erosion of refractory lining.

Keywords: Alumina, Silica, MnO, Sulphur, Slag rate, Coke rate, Cold strength.

Compaction Rollers for Sinter Productivity and Quality Improvement at Sinter Plant#3, Tata Steel Jamshedpur

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Sinter making is agglomeration of iron ore fines caused by incipient fusion by application of heat. Sinter is the most preferred burden which affects blast furnace (BF) productivity and coke rate. In this paper, it has been illustrated how sinter return fines which is the most important quality

parameter, has been improved by in-house developed compaction roller on sinter bed at Sinter Plant#3 in Tata Steel Jamshedpur.

It is established through both lab as well as industrial trials that best results with respect to productivity and quality of sinter are obtained when bulk density of sinter mix on pallet is maintained around 1.9-1.95 t/m^3. But the bulk density of top layers is always low at around 1.6 to 1.7 t/m^3. The same for middle and bottom layers are 1.9 - 2.0 t/m^3 and 2.2 t/m^3, respectively. As the bulk density of top layers was lower than required, the sinter formed in top layers tends to be weak leading to generation of higher return sinter. Hence, it was the endeavor of sinter makers to increase the bulk density of top layers.

For increasing the bulk density of top layers, a system comprising of 6 compaction rollers was developed in-house from simple belt conveyor idlers. Four rollers catering to both sides near side plates and two in the middle. These compaction rollers have been designed such that the compaction impacts only the 40-50 mm of top layer.

Three Plan-Do-Check-Act (PDCA) cycles were adopted in designing the rollers perfectly. After installation of compaction rollers, internal return fines generation was reduced by 2% and BF return fines by 1.5%, resulting in increased yield and higher sinter in BF burden.

Keywords: Sinter making, Blast furnace, Compaction roller, Return fines, PDCA.

Strategy to Enhance the Sinter Production after Planned Stoppage of machine-1 at Sinter Plant-3 in Bhilai Steel Plant

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In sinter plant, productivity is important parameter and it is achieved by continuous running of machine. However, some planned stoppages are taken to avoid breakdowns. The biggest challenge for the operators is to bring back the sinter machine to normal speed as soon as possible after the stoppage. This stabilization time is more in bigger machines as compared to small ones. Our machine is big machine with (4 m x 80 m) = 320 sq. m.

This paper deals with innovative practices used for reducing the stabilization time of sinter machine after planned stoppages.

Specific Productivity Improvement at SP1 of Tata Steel, Jamshedpur

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Sinter Plant 1 (SP1) of Tata Steel Jamshedpur works has registered a significant improvement in gross specific productivity over 60+ years of commissioning through numerous improvement initiatives. Subsequent increase of productivity posed challenges on circuit capacity to handle higher amount of load. The paper outlines the measures implemented at SP1 to overcome these challenges without major investment.

In green mix circuit, jamming of transfer chute and spillage required frequent cleaning by reducing the speed of sinter machine. Special anti-stick coatings were applied to reduce the material deposition in transfer chutes. In one of the long chute that was prone to repeated jamming, four nos. of timer based air blasters were installed. As a result of reduced jamming, calcined lime could be increased from 1% to 1.5% that enhanced sinter bed permeability. To address the material spillage in conveyors, several measures were taken such as; idlers were replaced with impact rubber pads to minimise conveyor sagging at receiving points, conventional scrappers were replaced with heavy duty scrappers, PT-Max Tru Track Idlers were used instead of common training idlers, and installtion of heavy duty side skirts.

Sinter bed permeability was increased after replacement of conventional single stage permeability bars with modified two stage bars. Leakages in suction system were significantly reduced by replacing traditional mild steel wind main component with Hardox Steel. Moreover, sinter cooler efficiency was increased by replacing fire retardant cermaic clothes with fire & heat resistant silica coated ceramic cloth that minimized burning of these sealing clothes.

These improvements enabled to increase sinter machine speed from 1.4 m/min to 1.7 m/min without compromising either on burn through temperatures or product sinter temperatues.

Above mentioned initiatives and modifications enabled SP1, the oldest sinter plant in India, to achieve an improvement of productivity from 37.5 t/m^2/d to 41.2 t/m^2/d.

Keywords: Sinter plant productivity improvement; Two stage permeability bars; Anti-stick coating; Air blaster.

Effect of using High Grade MnO Bearing Iron Ore on Sinter Properties and its Reduction Behavior in Upper and Lower Stack of Blast Furnace

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A low-grade iron ore with high percentage of MnO was used directly at JSW Steel Dolvi plant to determine its effect on sinter properties and its reduction behaviour in BF upper and lower stack. Results showed that with the use of low grade iron ore (0 to 20%), the sinter properties like tumbler index decreased from 74.3 to 73.6%. Sinter reduction degradation index (RDI) improved from 24.2 to 22.01 with 5% usage of low grade iron ore. However, on further increase in low grade iron ore (10-20%) the RDI found to be increased. This increase was attributed to the increase in hematite % of sinter. Reducibility index (RI) of sinter increased with increase in low grade iron ore (5 to15%) however, beyond 15% RI decreased by 2.9%.

Selective Addition of Sinter Return Fines during Granulation

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The proportion of ultrafine fraction in iron ore fines is increasing due to the deterioration of ore quality. The permeability of sinter bed is one of the important factors which controls sinter productivity and quality. Improving mean size of granules is one of the enablers of getting optimum bed permeability which can be done increasing lime addition, increasing mixing and granulation time, optimising moisture content etc. In the present work an attempt has been made to improve the granulation efficiency i.e. granulation index (GI) by delaying the addition of a proportion of sinter return fines in the mixing and nodulizing drum. When the proportion of bypassed sinter return fines was 50%, GI was found to be improved by 6-8 points with increase in sintering rate.

Sustaining Productivity of Sinter Machine when Mixer is under Maintenance

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Sintering of ore fines is an agglomeration process where the size of ore fines is increased by incipient fusion. Now-a-days super fluxed sinter is made which is an excellent raw material for hot metal production in blast furnace with reduced coke rate. For making good quality sinter, mixing and nodulizing of raw materials is very important.
Sinter machine 2 of Sinter Plant # 3 at BSP has suction area of 360 m^2 and is equipped with Eirich mixer and Eirich Noduliser for mixing and balling of sinter charge. Both are identical equipment and if mixer is down then sinter machine can be operated with noduliser at reduced capacity. This machine has the facility of lime dozing and lime is added in mixer only. If mixer is bypassed, burnt lime can't be added in sinter raw mix. Also, two stage water addition is done in mixer and in noduliser respectively. Whenever mixer is down, productivity of sinter machine goes down from 1.07 $t/m^2/hr$ to 0.69 $t/m^2/hr$ mainly due to the following factors:
a) lime is not added in sinter charge.
b) quantity of water is not sufficient.
To overcome above problem, lime addition facility was created in E1063 and water addition facility created in E1063 to E2003 chute and in belt weigher E.1021 and E.1031.
After this, water addition was made in auto mode for better control. The outcome of the above measures was as follows:

- Production increase resulted in the benefit of 1.2 crore per annum.
- Mixer can be spared for preventive maintenance.

Proactive Process Control in a Sinter Plant using Digital Platform

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Sinter is the most desired burden material for blast furnaces because its properties can be designed as per requirement. The demand for additional sinter of good quality is always there. The challenge

for a sinter maker is to minimise the variability in process and control it at the earliest possible instant. To address this, a new set of process parameters were designed to visualise the sinter making process in a better way. Some of these parameters are the bed filling index, carbon burning rate, on-line sinter bed permeability, charge density, and so on. Suitable standard operating procedures (SOPs) were made for these new parameters to continuously monitor and control these indices in a proactive manner. A system of visualising and monitoring of these parameters have been developed online, using digital platform. This has helped in improved process stability at Sinter Plant #2 of Tata Steel Jamshedpur works resulting in a reduction of sinter return fines by 2%, increase in productivity by 0.5 t/m^2/day and increase in reducibility index by 5%.

Integrated Battery Health Monitoring system at COB # 11, ISP Burnpur

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Coke Oven Battery (COB) 11 which was commissioned in February 2013 is a 7 m tall with dry quenching system consisting of 74 ovens with useful volume of 41.6 m^3. At present this battery is operating at a high pushing level. With the recent introduction of stringent norms for COB by Central Pollution Control Board (CPCB), coke oven health is in focus, as both oven health and environmental pollution are directly related. To take care of COB health under this condition and to prolong its service life, a joint project between RDCIS and ISP was taken up. Battery health is primarily defined by following parameters:

- Condition of the refractory brickwork.
- Condition of the battery bracing system.

The first condition was monitored through cross-leakage measurement and analysis of pushing force from individual ovens. The second condition was monitored through thermal imaging of the oven top focusing on the vulnerable areas where the bracing system (cross and longitudinal tie rods) are exposed to heat sources. All 156 AP bases were scanned using thermo-vision camera to identify the areas where refractories are damaged and need prior attention. The on-line pusher ram current profile was studied extensively and a methodology was developed for tracking oven wall conditions and thus to prevent hard pushes. The battery heating system was also studied and joint action was taken wherever required for regulation of heating. Using these observations, an integrated battery health monitoring system was developed. The system helped ISP in taking timely preventive repair actions and enhancing the overall battery health for improving and sustaining productivity and product quality.

Experience of Increased Calcined Lime to Improve Sinter Productivity

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In conventional BF-BOF route, the issues related to availability and variability of calibrated lump ores have shifted the focus of steel makers towards exploring consistent and more sustainable sources. Iron ore agglomerates provide a promising source of iron and can be customized to suit the BF requirements in achieving the hot metal quality suitable for BOF operations.
Vijayanagar works of JSW Steel Limited, currently operates with four units of sinter plants and three units of pelletizing plants, with a combined agglomerate production capacity of 29 MTPA to support the production of 12 MTPA hot metal and 1.2 MTPA DRI. The delayed commissioning of the pelletizing unit no. 3 due to Covid-19 pandemic called for the sintering units to increase their production to support the hot metal requirement as per the business plan. One of the tried and tested way to increase sinter usage was to increase the usage of calcined lime. Calcined lime acts as a binder in the granulation stages of sinter mixture and increases the permeability of the sinter bed for better productivity as well as fulfilling partial fluxing demands of sinter.
A trial was conducted at sinter plant having conventional drum mixer-nodulizer with a plan of step wise increase of calcined lime usage from 28 to 42 kg/t of sinter. The experience gained through this trial on the process and its effect on sintered iron ore products as well as necessary changes needed in supply chain to facilitate higher demand of calcined lime will be summarized.

Keywords: Sinter, Calcined lime, Productivity, Vertical Sintering speed, return fines circulation.

Operational Practices for Consistency in Pushings at Coke Ovens

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JSW Vijayanagar, operated eight stamp charged recovery coke oven batteries to fulfil the coke requirements of its four blast furnaces. The paper details the operational practices adopted to achieve consistent production for smooth functioning of the blast furnaces which operate with iron ore having high Fe% variability. A configuration management system has been established with options of CDQ and wet quenching, availability of spare battery machineries and cross battery operations which was further strengthened by regular interlock inspections and with the help of oven identification system for eliminating manual operational errors. Consistency in battery temperatures has been achieved by constantly tracking of temperature deviations and implementing necessary control actions for timely oven readiness. Further with consistency in battery temperatures ovens could be scheduled to achieve daily and monthly production plans and cycle time gap could be given in general shift hours for enhanced shutdown planning and preventive maintenance of battery machines. Further with focus on battery health, practices like door and frame cleaning, vertical flue and oven inspection, cleaning of gooseneck, standpipe and tar chasing have been standardised and maintained. More over any deviation in pressure exerted on heating wall during pushing are regularly monitored and corrected. All the ovens are periodically observed for refractory damages requiring ceramic welding or oven patching. Also parameters like timely pushing and charging are regularly monitored to observe and deviations in battery operations due to delays and breakdowns.

Keywords: Oven temperature, battery health, Ceramic welding, Pushing force.

Contemporary Approach against Blast Furnace Build ups

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Day by day Companies changing their raw materials selections towards lower qualities for cost effective operation. Lower qualities of Iron Ore and coals carries higher alkalis, ZnO and sulphur concentration to blast furnace. Alkali balancing is always challenging for most of the blast furnace operators especially furnaces equipped with copper staves which are very prone towards buildups for their intensive cooling efficiency. Its significance is realized only when problems like scaffolding and scabs formation leads to furnace irregularities. Alkali enters the furnace through the input raw material and leaves through the vapor phase into the flue dust and the tapped slag. Elemental sodium and potassium as well as their oxides are volatile with high vapor pressures.

Therefore they move up with the ascending gas stream and get absorbed by descending porous materials. Some of the alkalis also deposits on the cold areas of the stack. 90% alkali removal takes place through slag. Alkali behavior in blast furnace can be analyzed in terms of cycles and accumulation. In blast furnace alkali cycles cannot be avoided, but accumulation can be controlled. Sp alkali input to be restricted < 3.1 kg/thm. The day average alkali flushing should be > 85%. Weekly average >95% flushing to be ensured, if not flushed, then immediate actions shall be taken to achieve desired flushing. Specific fines load has to be controlled through screened flux during high flux rate operation, during unavoidable circumstances. Combination of both higher alkali and higher fines input have the highest tendency for build ups. Sinter chemistry should be optimized to decrease the raw flux rate at blast furnaces. Lower alkali input should be ensured to enhance the effectiveness of actions takes during the flushing charge given to furnaces. Flushing charge is designed with lower slag B2 formation mostly with charge of higher quartzite on the wall to remove preliminary build ups in bosh and belly region of furnaces. Furnace to be equipped with heat flux monitoring system for early capturing of build ups.

Keyword: Blast furnace, Flux rate, Alkali input, Alkali recirculation, Alkali buildups, Lower heat flux, Furnace irregularities, Lower production.

Reliability Improvement through Digitalization for Sustaining High PCI Rate in Blast Furnace Units, JSW Steel Ltd

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JSW Steel, Vijayanagar works is equipped with 4 Blast furnaces and 2 Corex units for Ironmaking. In-house development of "Mistake Proof" system for sustaining HIGH PCI rate (>200 Kg/thm), without compromising on Productivity (>2.88 t/m3/d), with-in a shortest span of 60 days. Facilitating and sustaining PCI rate > 200 kg/thm, in large BFs with existing challenges like high slag rate, unhealthy hearth and stove condition, wide variations in burden mix etc. through digitalization. Interruptions in PCI has major threat of chilled hearth and loss in production. Reliability plays a vital role in increasing in PCI. The following initiatives are taken 1) Early detection of coal valve failure by installation of temperature, pressure and flow sensors in the coal lines. 2) Installation of tuyere camera to avoid tuyere failure due to coal abrasion 3) Initiated auto purging of coal valves. 4) Installation of temperature sensors at blowpipe and developed algorithm to stop coal injection in case of increase in temperature. 5) Installation of pressure sensors in dome

valve for early detection of dome valve failure.

Keywords: Productivity, Technology, High PCI rate.

Experience of High Pellet Burden Operation in Blast Furnace at JSW Steel Limited

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The input raw material supplied to JSW steel Vijayanagar has high gangue content (Al_2O_3> 4.0 %, SiO_2 >7.0 %) from local mines. This is not directly used in agglomeration, they are beneficiated and used in further process. JSW Vijayanagar has 4 blast furnace units, 2 Corex unit and operates with normal burden for medium to large blast furnace (Working volume: 1462-3445 m^3) sinter: pellet:ore :: 60-65 % :20-25 % :15-20 %. As a strategy to reduce the conversion cost and processing of high gangue input, JSW installed India's largest pellet plant of 8 MTPA capacity and commissioned it in Mar'21. This steered the blast furnace unit to operate high pellet % in burden. There is no global reference of pellet properties with 3.5% Al_2O_3, 6.5%SiO_2. The pellet % in burden was ramped up slowly from 20 % to 40 %. This paper explains the major challenge with operating the blast furnace with high pellet burden ratio (high gangue), such as optimising the burden distribution, impact on techno-economic and productivity improvements. This paper also describes the optimisation of pellet composition to improve blast furnace efficiency.

Keywords: Large blast furnace, High Pellet operation, High gauge pellet, Productivity and Burden distribution.

Lime Fines Injection Trial at F Blast Furnace

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It is always a challenge for blast furnace to produce hot metal of low Si%. To lower down Si% in hot metal limes fines injection trial was taken at F Blast Furnace. Lime fines of similar size as fine coal used in blast furnace, were added/mixed along with fine coal and injected in furnace through tuyeres. we have targeted lime addition at the rate of 10 kg/thm. Trial was taken for 8 days. During the trial, it was observed that despite drop in bosh slag, there is drop in hot metal Si% --- which signifies the improvement in tuyere slag basicity and its effect on hot metal Si%.

Trial of ASRF as Charging Material in Blast Furnace

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In blast furnace process, sinter is considered as one of the most important raw material. At present, direct lump ore charging has been restricted to a limit in all the blast furnaces and maximising agglomerates charge for better blast furnace operation as well as utilising valuable waste iron bearing materials. To maintain good permeability of blast furnace sinter is being charged in blast furnace only after screening as there is a lot of fines present in sinter. As sinter fines contains same quality as the lump sinter, it also to be utilised in blast furnace. ASRF (Agglomerated Sinter Return Fines) is the material which is purely made from sinter fines mixing with some binders to give some shape. In C Blast Furnace of Tata Steel Ltd, successfully charged ASRF as 5% as burden material which not only utilised the waste fines but also improved in blast furnace operation. This paper will discuss about the effects and benefits of using ASRF as charge material in blast furnace.

Blow down and Salamander Tapping – Recent Experiences at Tata Steel Limited

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The blast furnace is still the most commercially viable and versatile method of iron making. The hearth repair or complete relining requires precise planning and execution to reduce the loss of business opportunities due to long down time. Hearth repair requires blowing down of furnace and salamander tapping, both activities are critical in nature and can prolong the down time if not carried out successfully and effectively.
At Tata Steel in recent past both salamander tapping and blow down were carried out both in smaller and bigger furnaces very effectively and in less time. Innovative methods have been used to carry out the blow down successfully where as new in-house developed drilling method was used for salamander tapping which enabled to evacuate about 100 tons of hot metal.
This paper encompasses the recent experiences and development in the blowing down and salamander tapping of blast furnaces at Tata Steel Limited.

Experience of Blast Furnace Operation with Very High Nut Coke

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Charging high amount of nut coke in blast furnace for lowering coke rate is always challenging. Problems like increase in permeability resistance in lower part, poor deadman, frequent small coke in tap hole and stoppage of metal & slag flow during cast etc. is generally observed which affects furnace performance. E and C BF of Tata Steel Ltd, successfully increased nut coke consumption from 45 kg/thm -75 kg/thm for reduction of coke rate and increase in productivity and significant benefit was achieved in both cases. This paper will discuss different aspects of high nut coke operation at E and C BF.

Keywords: Nut Coke, Coke Rate, Productivity, Deadman, Permeability Resistance.

Use of Low Grade Iron Ore Fines at JSW Dolvi Works – A Strategic Shift

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JSW Steel has seen a phenomenal expansion in last two decades and securing raw material is vital for sustainable operations. JSW has been trying very hard to acquire mines in recent decade and finally succeeded in FY21 with acquisition of mines in Odisha. Geologically, Odisha ore is soft in nature and contains very high ultra-fines upto 35-40%. The biggest challenge for Dolvi works was to consume large quantity of captive ore mostly low and medium grade fines with Fe content as low as 59-60%. Detrimental gangue content like alumina and silica was as high as 9-10% which was posing severe challenges in iron making operation and quality. Use of high alumina sinter and pellet plants led to high slag rate of 460 kg/thm in blast furnace. To deal with these ore, both agglomeration and iron production units implemented strategic changes in their processes. To achieve smooth operation, several modifications in process and standard operative practice were adopted to maximize productivity and quality in upstream. Integration of captive mines and successful transition of operation led to cost benefits and raw material security for 10 MTPA steel production at Dolvi works.

Keywords: Captive mines, Alumina, Silica, Slag rate, Strategy, Cost & Timely availability.

Sustaining Hot Metal Production in Blast Furnace with High Slag Volume Operation @ JSW Steel Ltd, Salem Works

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JSW Steel Ltd, Salem is 1.0MTPA integrated special alloy steel plant with two mini blast furnaces (BFs) with useful volume of 402 m^3 and 640 m^3. BF produces liquid hot metal from raw materials and supply to steel melting shop.
Hot metal production was in the range of 1850 – 1900 tons per day (tpd) in BF2 with 380 kilograms per tonne of hot metal (kg/thm) with premier grade (high Fe, low SiO_2 and low Al_2O_3) raw material. Due to the non-availability of premier grade raw material, low grade raw material (low Fe, high SiO_2 and high Al_2O_3) was used and it resulted in high slag volume of ~ 440 kg/thm. Frequent self-slips, in-wall temperature fluctuations, heat load deviation, improper liquid drainage were observed with high slag volume and were unable to sustain the hot metal production which was achieved with low slag volume operation. Due to this, hot metal production got reduced to 1720 TPD and pulverised coal injection (PCI) got reduced from 145 to 100 kg/thm. Slag generation rate and liquid ratio were crossing the defined limits.
In order to sustain the hot metal production with high slag volume, detailed brainstorming was done internally and also with other plant team. It was analysed by calculations that raw material rolling was happening from the preceding ring to periphery. This was the primary reason for abnormal furnace behaviour and also furnace could not operate in a stable way with high slag volume. Burden distribution was adjusted by using the final peripheral ring also for coke and IBM (Iron Bearing Material) dumping.
Due to these actions, blast Furnace could produce around 90 to 100 tpd above the earlier limit. Also, PCI rate was increased from 100 to 125 kg/thm.

Keywords: High Slag volume, Self-Slip, Burden Distribution.

Usage of ASRF at Blast Furnace to Reduce Carbon Rate at Tata Steel Limited

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Blast furnace process discards usage of fine material as it is detrimental for process stability. Lot of fines are generated during raw material screening namely sinter return fines, ore return fines, coke return fines etc. Any initiative to consume those fines material in blast furnace without affecting process stability will result in putting emphasis on sustenance.

At Tata Steel in recent past a new material is tried namely ASRF (Agglomerated Sinter Return Fines) which is basically agglomerating the return fines of sinter. It is designed and produced and trial is taken at C Blast Furnace of Tata Steel and the results were encouraging and about reduction in carbon rate of about 5 kg/thm is seen.

This paper encompasses the recent experiences and learning on usage of new material namely ASRF at Tata Steel Limited.

Experience in Blast Furnace Hearth Repair

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On June 24, 2020, after start up from 77 days of banking and producing 6.32 million metric tons of iron, Tata Steel's blast furnace experienced a reduction in hearth wall thickness (<400 mm). The blast furnace was commissioned in the year 1924 and was still running in the 14th relining campaign done in 2009 having an inner volume of 1078 m^3, with 20 tuyeres, used tar as auxiliary

fuel, two tapholes and 4 inner combustion stoves.
To extend the life of C Blast furnace hearth repair was planned in Nov 2020 and the repair duration took 45 days. Hearth repair is a unique activity and is equivalent to relining of a furnace. Hearth repair activities included successful blowdown, in-house arrangement for salamander tapping, removal of hearth carbon blocks, refractories and replacing them with new one. During the repair, 58 new thermocouples were installed in the hearth, concentrating on the tapholes and elephant foot areas to monitor heat flux calculations. This hearth monitoring system has already identified other problem areas and provided valuable information about hearth drainage patterns. This write up aims at highlighting the major enabling jobs, innovations, initiatives and explorations in course of hearth repair.

Optimization of Specific Metallurgical Coke Consumption & Hot Metal Cost at Blast Furnaces of Vizag Steel, RINL

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Production of hot metal from blast furnaces of Vizag steel, RINL was affected severely because of crisis in availability of metallurgical coke due to less no of pushing at coke oven batteries. Achieving desired level of production with available metallurgical coke was a great challenge to the blast furnace operators. Use of more nut coke & substantial increase in pulverized coal injection for each blast furnaces need to be implemented without jeopardizing the furnace behaviors. All the enabling parameters and related logistics were critically analyzed to replace metallurgical coke with nut coke & more PCI simultaneously. Furnace operating parameters were monitored very closely; new regimes were set for individual furnaces to bring down specific metallurgical coke consumption per ton of hot metal to an optimum level & maintain same level of hot metal production on daily basis with the reduction in hot metal cost. Injection could improve close to 150 kg/thm in BF3 and subsequently in BF2 and BF1 with consistent efforts and suitable changes in operating philosophy as brought out vividly in the paper.

Keywords: blast furnace, metallurgical coke, nut coke, pulverized coal injection, hot metal cost.

Reviving the Reduction Shaft Operational Life at COREX, JSW Steel

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COREX is the one of the new commercially and technologically proven alternate routes of iron making. Low Shaft Life became a challenge for COREX Operation. Shaft life signifies the continuous running of shaft before performing shaft empty shutdown, where the shaft is made empty, manpower enters into the shaft to clean the bustle ports manually, which is quite a tough job. The deterioration shaft performance dropped from 120 days to 60 days. There was a gradual deterioration in feed pellet quality and coal quality to the COREX unit, over the years. After installation of arial gas distributor in the shaft, the shaft became sensitive to change in pellet quality. Every reason for lower shaft life was analysed and categorized. The major reasons for low shaft life was attributed to the jamming of DRI screws, jamming of bustle ports, jamming of engineering ducts, etc. The major reasons were further drill downed further with appropriate remedial action. The low shaft life was correlated to the pellet input quality. Hence, the pellet input raw materials plant operational parameters were inter-linked. The pellet production was again related to the business model of the pant. The following improvements effected could improve the shaft life. Periodic and proper cleaning of the bustle ports, installation and changing of the Grizzly rods design on bunker top to prevent entering of bigger size coke or foreign materials, installation of stock house pellet screening process, increasing reduction gas temperature and maintaining uniform in-burden temperatures that ensures gas distribution in the shaft, improving alkali, zinc, sulphur balance in the furnace, redesigning the slag chemistry, re-establishing coal selection criteria etc could improve the shaft life. Some of the parameters were continuously monitored online. The actions taken on the various operational parameters improved the performance of reduction shaft during of operation close to 90 days with improved techno-economics even with varying pellet quality.

Keywords: Deterioration of Shaft Life, Quality Improvement Programs, Process Parameters Optimization.

Utilization of Cow dung in the Reduction Roasting of Iron Ore in Hybrid Microwave Furnace

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The reduction of iron ore using cow dung has introduced a new era because of its contribution to energy and emission reduction. Cow dung (fixed carbon: 9.33%, volatile matter 43.68%) used as the reductant in the reduction roasting of iron ore in a hybrid microwave furnace with a frequency of 2.45 GHz and maximum power of 4 kW. The optimum conditions of roasting as determined by taguchi stastistical design were found to be temperature: 900°C, time: 5 minute and reductant to feed ratio: 0.4. The magnetization of microwave treated samples were determined using vibrating sample magnetometer (VSM). Characterization studies indicate the formation of magnetite phase under optimum conditions resulting higher total magnetism saturation of the sample. The magnetic susceptibility and saturation magnetization of lean iron ore using cow dung as reductant very effectively enhanced by converting hematite to magnetite at the optimum condition using a controlled hybrid microwave furnace.

Keywords: Lean Iron Ore, Hybrid Microwave furnace, Cow dung, Reduction roasting, Saturation magnetization.

Enhancement of LD Converter Bottom Purging Plug Life

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Bottom purging plays important role in controlling in slag-metal reactions in LD converter. It helps in keeping in tap phosphorus lower and hence is vital during processing of automotive and electrical steels. Normally, the life of the bottom plugs is lower than the average converter life and steels makers always struggle to keep the bottom purging open till the end of the converter campaign. The multi hole refractory plug (MHP) made of MgO-C refractory material have been

introduced, which results in more gaseous surface area during the purging and help in better mixing and mass transfer in converter. These multi hole refractory plug, though improve the process efficiency, they are prone to metal trickling, non-uniform and faster erosion and often leads to puncturing. To avoid this issue, JSW Vijayanagar works, introduced a customized bottom base block in its multi hole refractory plug design which strengthened the plug fixture and reduced the tickling instances. It also introduced optimized gas flow patterns for initial blow period, blow end period and post blow period purging which reduced the non-uniform erosion. It developed a unique plug condition prediction system based on the laser scanning report which helped in plug specific maintenance. These initiatives helped in increasing the availability of multi hole refractory plug purging from 70% to >95% of the converter campaign.

Keywords: Refractory, MHP, VAS.

Utilization of LF Slag for Sustainable Steel Making and Improvement in Steel Quality

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In the year 1911, Tata Steel installed its first steel melting shop. LD#2 & Slab Caster came into operation in the Year 1993. LD shop have three different sections to convert hot metal to slab, namely primary steel making, secondary steel making and slab caster.

This paper primarily deals with the elimination of spar and reduction in lime consumption in ladle furnace. Currently at LD2-LF, lime is added along with spar as a fluxing agent. However, there are environmental concerns regarding using fluorspar and it has a corrosive effect on the ladle refractory. Flour can be lost from industrial slags due to the reaction $2CaF_{2(slag)}+SiO_{2(slag)} \rightarrow SiF_{4(g)}+2CaO_{(slag)}$. If it reacts with water it forms hydrogen fluoride fumes, which is toxic and dangerous. Synthetic slag can act as suitable agent but it is costly. LF slag has advantage over fluorspar by being low cost and less environment harmful which can help to replace spar. Sample collected from IBMD. LF slag composition is given below:

CaO	Al_2O_3	Fe	S	MgO	SiO_2
55	35	0.7	0.42	3.5	3.5

LF slag has low FeO Content, good Cao and alumina content which will help in early slag formation and desulphurization. LF slag has 55% CaO content it helps in reduction of lime consumption. The trial of LF slag lump was planned and train methodology given below.

1.LF slag addition 200 kg/heat
2.Lime addition reduced 100 kg/heat (55% CaO in slag)
3.No spar addition in all trail heats.
Good slag formation and desulphurization were observed. I hereby conclude lime and spar also saved.

Development of Simulative Test Method of Ladle Filler Sand to Ensure Steel Ladle free Opening Performance

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Ladle sand is used in secondary steel making for holding the liquid steel inside the steel ladle for certain period of time and then allow to free flow the molten steel along with sand once the slide plate is opened. Ladle sand forms a soft sintered layer at the contact of the molten steel which remains at semi liquid state while at temperature. The ferro static pressure exerted by the steel usually breaks the sintered layer of sand. But sometimes the sintered layer becomes strong enough that it creates a barrier in steel flow that out turns to non-free opening. Non-free opening causes disruption in production, stoppages of casting process, re-oxidation of steel and others. Moreover, it affects the cleanliness of steel as well as creates unsafe environment while doing oxygen lancing to split the frozen material. The performance of the sand depends on material intrinsic properties together with different operational variables. The prerequisite of the sand is to provide an appropriate sintered layer even with long times exposure in high temperature at application area. Like other refractory material the behaviour of the sand at cold condition is quite different that at operating temperature. In the present work, simulative test properties are designed to characterise ladle sand that will fits into the process mechanics to maximise the probability of zero non-free opening.

Use of Statistical Tools to Improve the Strike Rate of EWNR Grade of Steel

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EWNR (Electrode welding non-rimming) is a non-rimming continuous cast substitute of conventional rimming steel produced through ingot route of casting. Main application of this grade is for making arc welding stick electrode wires. Due to compositional requirement of the grade, the amounts of major de-oxidants are restricted, which in turn makes it very difficult to control dissolved oxygen in liquid steel. The main challenges of manufacturing this grade of steel in open casting are to meet the chemistry as specified/ required by customers, maintain low dissolved oxygen during steel making process, trouble free casting and billets free from blow holes and pin holes.

Regression analysis was done to find out probable causes of grade diversions due to chemistry. Broader variations in process parameters are compared using box plot. The actual source of process parameters variations was reconfirmed with the use of Shinine techniques and finally fixed the specification limits of confirmed cause of process deviation by why-why analysis and technical expertise. The findings of the project can be applied to other low carbon open cast grade of steels where percentage silicon is restricted due to specifications limit and the steel cannot be killed with use of aluminum due to open casting castability issues. Before the start of the investigation, the strike rate of this grade was 82%. After implementing the changes in operating practices, the strike rate improves to 90%.

Keywords*:* Deoxidation, Strike rate, Shinine Technique, Scatter chart, Open casting.

Recycling of LF Slag as a Sustainable Solution to Reduce Environmental Impact

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Ladle furnace (LF) slag is a by-product produced during secondary steel making process. At secondary steel making, huge amount of slag is generated post LF treatment which gets dumped owing to size issue thereby leading to land filling which is a sheer waste of valuables as well as an environmental concern. Slag generated from Al-killed steel has relatively high CaO-Al_2O_3 content that can be recycled and used at LF as an alternative to costly synthetic slag and fluorspar. Currently, fluorspar along with lime is used as a fluxing agent at ladle furnace. Though fluorspar is a powerful fluxing agent, it has a corrosive effect on the ladle refractory and is also environmentally harmful for which its benefits are to be weighed against health and environmental concerns. The LF slag generated from Al-killed grades having lower oxidizing potential and good CaO-Al_2O_3 content can act as suitable slag conditioner over costly synthetic slag and harmful fluorspar. With the stringent environment norms for waste disposal, an approach was adopted for recycling the LF slag by briquetting them into suitable size and shape so that they can be reused thereby implementing the principles of 3R (reduce, recycle and reuse). The current paper focusses on the plant trials that were done for recycling of finer LF slag. This project aims at 100% recycling of AL-killed LF slag. Impact of trials on lime consumption, fluorspar (CaF_2) consumption, desulphurization rate and processing time were studied. The study helped to eliminate dumping of LF slag by recycling it thereby reducing lime and CaF_2 consumption at plant.

Keywords: Recycling, LF slag, Desulphurization rate.

An Efficient Deoxidiser for Steel

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It is well established that oxides are the main non-metallic inclusions in steel, and the cleanliness of steel is usually reflected by total oxygen content. Removal of oxygen from liquid steel without affecting the quality has always been a challenge. As ultra-low inclusion level has become the need of the day, starting with an oxygen level of 300-1000 ppm after primary steelmaking the steelmakers always struggle to remove the oxygen efficiently and keep the melt free from harmful deoxidation products. Conventional aluminum based deoxidation has two demerits, (a) cost is high (b) It leads to formation of solid deoxidation products - endogenous inclusions; removal of which poses problem. Hence, there was always a need for an alternate deoxidizer which can alleviate the above problems. JAMIPOL has come up with an innovative and cost effective deoxidation solution which provided a great relief to steelmakers. This process uses a lime rich deoxidizer along with other constituents and slag modifiers. This new reagent has addressed all the above two issues. This deoxidation process not only satisfies the steel quality requirement, but also reduces deoxidation cost & increases its efficiency. Additionally, presence of certain innovative constituents helps in easy removal of inclusions produced during deoxidation. The new deoxidising reagent partially replaces aluminum (22%) and lime (14%) which resulted in reduction of total cost of deoxidation by around 8%. Simultaneously, there was a significant improvement in inclusion level in the steel too.

Effect of ESR and VD route on J1C-Fracture Toughness of Ni-Cr-Mo-V Steel

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The vacuum degassing (VD) route is generally preferred for low-cost steel forgings. However, the inclusions (metallic/non-metallic) are profoundly present in the VD route, and it may degrade the fracture toughness behaviour. On the other hand, electroslag remelting (ESR) is mostly used to obtain clean steel with lesser inclusion fractions. The Ni-Cr-Mo-V Steel was developed by both, VD and ESR routes, and it was found that the inclusions rating of 1-1.5 and 1.0 severity in VD and ESR route, respectively. The fracture toughness-J_{IC} tests were performed on specimens from both routes. It was observed that the VD routed has a relatively lesser fracture toughness than the ESR, because of the higher inclusion rating in the former route. Moreover, a wide variation in J_{IC} was observed in VD route due to inhomogeneous distribution of inclusions. The fractography of the sample with a lower J_{IC} value in the VD route reveals the clusters of closely spaced inclusions. The closely spaced inclusions reduce the surface energy, where the coalescence of voids can lead to faster crack growth. In contrast, the higher fracture toughness in ESR process is due to a lesser inclusion fraction and can be used for forgings where higher structural integrity is required.

Keywords: Ni-Cr-Mo-V Steel, VD, ESR, Fracture toughness-J_{IC}.

Development of a Fibre Optic Temperature Measurement Technique for Tube Moulds

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Billet casting is used worldwide to produce long products such as concrete reinforcement bars, high carbon springs, mild steel wires and electrodes. Many product defects have their origins in the continuous casting mould. To understand the defects and the casting mechanism, temperature data and calculation of the heat flux is essential. Due to the constraint of space it has always been a challenge to use the conventional two wire thermocouples in the billet casting mould. In this paper, the development of a Fibre Bragg Grating based temperature sensing system for a billet casting mould has been described. It was installed in a caster at Tata Steel, Jamshedpur, and the real-time data from the mould during casting was captured over the life of the mould.

Key Words: Billet Casting, Billet Caster Mould, Temperature sensor for Billet Caster Mould.

Innovative Roll Profile Design for Thin Strip Cold Rolling Mills

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This paper presents the innovative roll profile design to achieve greater reductions on a cold rolling mill to produce much lighter gauges in lesser passes without compromising on strip shape. This study is based on the simulation of roll separating force applied on models with different roll profiles and analyses the stress distribution across the rolls and the strip. The study also includes the thermal analysis of YOGIJI-DIGI supplied 6-HI reversing cold rolling mills with more pass reduction for similar incoming strip thickness compared to other mills and the significance of strip, coolant and roll temperatures in the cold rolling process. The paper also concludes how the innovative roll profile has led to the environment friendly GREEN COLD ROLLING MILLS™.

Keywords: Roll profile design, Thin strip cold rolling mills.

Increasing the Sequence Length at the Thick Slab Caster

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At TATA Steel Jamshedpur, there are three thick slab casters which cater to a host of different customers, both in the automotive sector and outside. In order to meet this large demand, it is vital that production is optimized, and cost minimized to the largest extent possible. In the present infrastructure, flying tundish change (FTC) is done after every sequence to ascertain caster continuity and maintain high values of metal in mould. Every FTC requires for the caster to be brought to zero speed for a few minutes and as it is a process that is inherent to slab casting, one of the most crucial levers in achieving the annual targets is increasing the sequence length of all three casters to reduce speed losses and amplify the production throughput.
Currently, a submerged entry nozzle (SEN) is used as a channel to transfer the liquid steel from the tundish into the mould. As it is essentially a refractory material, it is subjected to continuous wear and is therefore susceptible to breakage. To tackle this, there is a practice of SEN change that is done three-four times in a sequence. In the current work, the effect of the SEN life on sequence length has been dealt with in great detail. The erosion patterns of the SEN were studied to better understand the cases of premature SEN failures. Based on the results of the study, the ramping pattern of the SEN was modified by employing an extensive design of experiment which have resulted in an increase in overall sequence length by 10% in the last 6 months.

Keywords: Slab Caster, Sequence length.

Elimination of Sticking Tendency in Low Nickel Austenitic Stainless during Continuous Slab Casting

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201LN grade (designated as UNS S20153 as per ASTM A240 Std.) is a 16Cr-4Ni-7Mn austenitic stainless steel mainly used in cryogenic application due to its superior mechanical and fabrication properties with excellent low temperature toughness. During the continuous casting process, this grade is found to have sticking tendency in the mould for slabs cast in width > 1500 mm. Due to this heavy sticking observation on the slab surface, excessive grinding has to be done to remove the defect prior to hot rolling which eventually led to a decline in the overall material yield and productivity. Elimination of this defect with subsequent minimization of grinding loss has been the main purpose of this study. To determine the root cause of this defect, various casting process parameters along with the steel chemistry were analyzed. It was observed that the heats cast with higher hydrogen and nitrogen content were majorly affected with this slab sticking issue. Analytical tool was also run considering all critical variables which also had similar sort of findings. Literature survey was carried out to correlate the statistical findings with the actual contributing mechanism. It was found that higher hydrogen in liquid steel enhanced the crystallization behaviour of the mould slag, thereby affecting the melting characteristics of slag and required heat transfer from steel to mould. This resulted in lower lubrication and increased sticker tendency. Additionally, slabs affected with sticking were also found to have higher casting speed which may have aggravated the lower lubrication condition. Based on the process study and analysis, suitable modification in chemistry were suggested and further optimization in casting parameters were carried out. The trial heats cast with the recommended chemistry of lower hydrogen & nitrogen along with restricted casting speed were found to be complete free from sticking defect. This significant improvement resulted in reduced grinding loss and overall yield improvement by ~8%.

Keywords: Low Nickel Austenitic Stainless Steel, Chemistry, Casting Parameters, Slab surface defects.

Reduction of Mould Level Fluctuation and Edge Cracks in Continuous Cast Slabs for Steel Grades with High Mn (>3%) and Alloys

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High manganese steels (Mn >=3%) exhibit high strengths and exceptional plasticity, hence they are a promising material for the automotive industry. But, continuous casting of high Mn steels is difficult as there are quality issues in the cast slab. Bulging of the cast product is observed and poor high temperature ductility of the steel which promotes cracking in the steel. Especially steels with greater than 3% Mn and with Ti greater than 0.1% show, fine edge cracks on the narrow face, which manifests as edge burst defect in hot rolling. The above defects could be overcome after various analysis. It was found that during continuous casting, the mould level fluctuations leads to improper shell formation in the mould and in addition, the poor high temperature ductility creates cracks in the slab product, making it unsuitable for hot rolling operation. A series of corrective action that includes improved steel chemistry with the boron and nitrogen content, improved the mould oscillation parameters, reduction in specific water consumption and maintenance of proper temperature during the unbending and straightening operation along with a focused control on mould level fluctuation could eliminate the crack and ensure despatch of defect free rolled steel product.

Keywords: Mould level fluctuation, Mould Oscillation curve, Edge cracks.

Prediction of Slag Composition & Optimization of Raw Flux through Matrix Operation at I Blast Furnace, TATA STEEL

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In blast furnace route of ironmaking, the quality of input raw materials plays a dominant role in determining the composition of hot metal and by-product slag. With an aim to increase furnace productivity and reduce fuel consumption, globally, blast furnace operators try to minimise slag rate and raw flux rate through estimation of the alumina input and flux addition into the furnace. However, due to continuous variation in raw material chemistry, traditional estimation techniques become a cumbersome and reactive approach leading to significant gap between the estimated and actual value. In the present work, an attempt is made to bridge the gap between predicted slag composition and actual slag chemistry by encapsulating the theoretical burden calculation with the flux optimization technique. The burden calculation model captures the real-time chemistry of raw materials which allows optimisation of flux amount using matrix operations iteratively to forecast the chemical composition of the slag with 96% accuracy. Based on the forecasted slag composition for the selected burden materials, the best combination of fluxes is determined through prioritisation technique that closely meets the slag composition in the desired range, thereby, allowing to achieve optimum slag rate and reduced flux consumption. This novel method of burden calculation has resulted in curtailment of variability in slag composition leading to minimized slag rate combined with stable furnace operation.

Keywords: Blast Furnace, Hot Metal, Slag Rate, Productivity, Flux Rate.

Achieving Excellence in Hot Metal Quality through High Slag Basicity and Optimization of Gas Flow Pattern at I Blast Furnace, TATA Steel

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Over the years, silicon and sulphur content of hot metal have been considered as two important parameters determining the quality of hot metal and blast furnace performance. A major focus has been given in controlling them within a desired band to reduce flux consumption at steel making units, thereby, cutting down the end-product steel prices. In Tata Steel blast furnaces, due to constraint in raw material composition, hot metal silicon used to be in the range of 0.8% to 0.9% which is much higher than world benchmark figures of 0.3% to 0.4% at European and Japanese blast furnaces. Lately, several initiatives have been taken for improving hot metal quality at TATA Steel, Jamshedpur. This paper presents a recent study using FactSage software, where it was verified that high slag basicity operation leads to reduction in both silicon and sulphur content of hot metal. But a slag with higher basicity also possess a major challenge of alkali removal through slag. However, high RAFT in front of the tuyeres along with high central working promotes gasification of alkali and facilitates their discharge through furnace top. A similar approach was carried out at I Blast Furnace, Tata Steel Jamshedpur, where, a slag basicity of CaO/SiO_2 greater than 1.1% is maintained resulting in reduction of silicon content by 35% and sulphur content by 30% approximately. Nonetheless, the challenge of alkali removal through slag was overcome by maintaining high RAFT (greater than 2200 ^{o}C) and high centre coke operation (greater than 25%) allowing alkali removal through blast furnace top gas.

Keywords: Blast furnaces, RAFT, FactSage software, slag basicity, central working.

Optimization of Power Consumption Opportunity in Cryogenic Air Separation Plant at RINL

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RINL over the year is producing 6.3 MT of liquid steel and after modernization and revamping it will be 7.3 MT of steel. Air separation plant plays a vital role in the steel making, blast furnace Enrichment and steel refining process and also other plant requirement. At present, 5 units are in operation, in which 3 units are based on old technology with tray type distillation column and other 2 units are based on new technology that is structural packed type distillation column. The main process of ASP, air is sucked from the atmosphere through pulse dry type filters where dust is removed and then compressed in a compressor to 6.4 kg/cm^2. The air is pre-cooled in air water tower to 10-16 °C and sent to the purification unit for the removal of moisture, CO_2 and hydrocarbons. The purified air is distributed in different streams for further compression/expansion and is fed into the distillation column through heat exchanger. The final products from distillation column are liquid and gaseous O_2, liquid and gaseous N_2 and argon. Gaseous products are further compressed to the required pressure and distributed through the plant for iron, steel making process. Liquid product is filled in the respective storage tanks. ASP is also involved additionally, in selling liquids to outer agencies. O_2 enrichment technology in BF reduces the amount of heat lost in exhaust gas and improves the efficiency of combustion. The demand for oxygen is expected to grow further. So there is an urgent need to meet the oxygen demand for which various innovative methods were adopted at our ASP to produce beyond the rated capacity. Energy consumption in Air Separation Plant (ASP) is the major issue of concern for steel plant economics. Thermal power plant is the main source of energy for VSP. Recent concern in the energy horizon is that, the cost per ton of steel produced should be minimum and also aid in further energy saving possibility. The purpose of this paper is to discuss various operational parameters and methods for efficient utilization of ASP and the concept of energy conservation.

Controlling Chemistry of HC Ferro Manganese: Our Experience

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Input phosphorus control is extremely important for any steel maker and is especially true at Tata Steel Kalinganagar which is producing high end flat product grades, like high tensile HSLA grades and peritectic micro-alloyed grades that have very strict tolerances in allowable phosphorus levels. Unfortunately, there is an increase in the phosphorus in manganese ores from our mines in Odisha as the mine deepens. As phosphorus control in a reducing submerged arc furnace making ferromanganese is not possible, it is important to control the phosphorus levels in the inputs. With phosphorus levels in domestic manganese ore rising, imported manganese ore up to the extent of 40% was used along with and low phosphorus LAM Coke. However, the increased use of imported ore led to the increase in silicon content of the FeMn as the imported ore has a higher silica content unlike Joda ore. The paper describes how a judicious control of the input ingredients was achieved to be able to supply ferro manganese with both, a controlled level of phosphorus and a controlled level of silicon.

Keywords: Phosphorus, Silicon, Control, Ferro Manganese.

Make-in-India Synthetic Flux for Desulphurization of Hot Metal in KR Process

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In the pre-treatment station of JSW Steel, fluorspar was used as the flux for desulphurization of hot metal through KR process and is generally imported. As a support to the “Make-in-India” drive, synthetic flux processed indigenously was used as a replacement of fluorspar. Due to its lower melting point, it dissolves easily rendering faster dissolution of lime and thereby faster

desulphurization. This led to a reduction in specific consumption of the flux by 15% and increase in average sulphur drop after treatment by 50 ppm, indicating better sulphur holding capacity of the slag. Furthermore, use of the synthetic flux makes the slag non-sticky, thereby improving the raking efficiency and reducing the handling loss. While the raking time got reduced by 2 minutes, an 8% increase in hot metal ladle life could be achieved due to less metal jamming and anchoring frequency. This not only helped in improving the quality, but also resulted in decreased conversion cost.

Keywords: KR Process, fluorspar, desulphurization.

Improvement in Quality of In-House MgO-C Bricks At LDBP, RSP

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Steel Melting Shop-II of Rourkela Steel Plant produces steel through BOF-LF-CC route. Shop has been provided with two BOF of 150 tons capacity and steel ladles. Magnesia carbon (MgO-C) bricks are used as working lining material in all the ladles. These bricks are being supplied by different refractory manufacturers including Lime Dolomite Brick Plant (LDBP), an in-house facility of RSP. A project was undertaken to improve the in-house bricks quality for improvement in lining life of steel ladles.
Based on the wear profile, zonal lining w.r.t quality and thickness has been designed. As a quality control measure, green bulk density of bricks was checked regularly during manufacturing. Modification in granulometry, graphite and anti-oxidant content was done for improved slag and oxidation resistance. Lining lives of 134 and 146 heats (average: 140 heats) could be achieved with improved trial bricks as against existing average lining life of 127 heats.

Products

KEYNOTE LECTURES

Phase Transformations in High Strength Steels

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Dilatometer is perhaps the most useful experimental technique to study phase transformations in steels. It can detect the transformation as it happens and can be used to quantify the progress of transformation for a given thermal or thermo-mechanical treatment. It is therefore used extensively to study different aspects of transformation and to design new steels and optimize the processing parameters.

The dilatation in the phase transformation zone between the start and the end temperatures is a resultant of the (a) change in the fraction and composition of the phases and (b) thermal expansion or contraction of the phases involved as determined by their respective linear thermal expansion coefficient values. A new method has been developed to extract these data directly from the observed dilatation. The new method has been used to (a) identify the stages of formation of austenite (γ) from a mixture of ferrite and pearlite during continuous heating, (b) understand the unusual expansion associated with the formation of austenite in a low alloy steel containing about 1 wt% Al, (c) to get an insight into the nature of bainite (α_b) transformation on continuous cooling, and (d) to understand martensite transformation on continuous cooling.

Some more interesting results on the solubility of carbon in bainitic ferrite and the corresponding position of the T_o line obtained from studies of isothermal bainite transformation would be presented. It would be shown that the results can be rationalised in terms of a displacive mechanism of bainite transformation.

These results on the fundamental aspects of transformation are then used to understand the evolution of microstructure in low-carbon, low-alloy multiphase TRIP aided steels and Q&P steels.

Additive Manufacturing of Metallic Materials: Processing-microstructure-property Relationship

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Additive manufacturing is being perceived as a game changer in the manufacturing sector. At present, the most widely used materials are nickel based superalloys and titanium alloys. The components of turbine engines are manufactured following complicated routes of processing, that makes these products expensive. Additive manufacturing being a net-shape technology provides an amicable solution to these problems. Similarly, patient specific orthopaedic implants can also be potentially manufactured using additive manufacturing, which are made using stainless steels and titanium alloys. In this presentation, a comparison will be made to bring out differences in the microstructural features and mechanical properties in Inconel 718 prepared by two methods of additive manufacturing, namely Selective Laser Melting (SLM) and Electron Beam Melting (EBM). The standardized heat treatment schedule for both the processes will be depicted and it will be shown that different heat treatment strategies are required for Inconel 718 manufactured by different methods. A similar proposition will be made for the necessity of evolving an appropriate heat treatment strategy for additively manufactured titanium alloys.

On Production, Processing, Properties and Applications of Hot Rolled HSLA Steels

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With India having established itself as the second largest steel producer in the world, it has an ambitious plan of producing 250 million tons of crude steel by 2030. With the kind of existing robust steel demand supported by the country’s competitive advantage, increasing investment in the sector and policy support from the Government, it can only be surmised that increasing amounts of high strength low alloy (HSLA) steels will be consumed across various end user segments. The ever-present demands for higher yield strengths, better weldability, good cold forming, particularly bendability as well as through-thickness fracture toughness, high resistance to brittle cleavage fracture and low energy ductile fractures have been met as increasingly knowledge was gained on the inter-relationships between microstructures and mechanical properties. While scanning over the developments in HSLA steels since its inception, it is seen that the thermo-mechanical processing when combined effectively with phase transformations, becomes a powerful tool to develop and control microstructures, unattainable by either route separately. The search for improved HSLA steels will continue by perhaps with more difficulty as attempts are continuously being made to take advantage of every trace of strength, ductility and toughness. In a future of scarce raw materials and energy crisis, it remains uneconomical to employ steels other than those offering the maximum potential. In this talk, it will be briefly reviewed that HSLA steels meet this challenge by offering an optimum balance of properties (as mandated by its end application) per unit cost.

ORAL PRESENTATIONS

Optimization of Mechanical Properties of SAE 9254 through Heat Treatments

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Considering the stringent norms being implemented by the governments worldwide, the demand to reduce the weight of suspension coil springs for automobiles is being foreseen in steel and automobile manufacturing companies. Not only the suspension springs become lighter, they also need to bear very high loads, thus demanding the development of very high strength steels with less weight. Judicious selection of alloying elements based on profound scientific/technological considerations might result in achieving this objective although it is expensive and time consuming. Another strategy could be optimization of heat treatment parameters and on technology basis the conventional heat treatment technique is a convenient and economical one. With this understanding, our efforts were to include variation of several heat treatment parameters (austenitization and/or tempering) on classic spring material, SAE 9254 supplied by the JSW Steels. Heat treatments were carried out on a hot rolled wire rod with varying austenitization temperatures and times to examine the effect of prior austenite grain size on the mechanical properties, primarily hardness and tensile properties. Microstructural characterization was done using optical microscopy, scanning electron microscopy coupled with electron backscatter diffraction methods. The properties attained for the current grade are comparable to the similar properties of the steels achieved after microalloying additions. A strength of more than 2100 MPa (UTS) and a reduction in area in excess of 30 % was attainable, as revealed by our investigations. This talk will present the dependence of mechanical properties on the microstructural features in the SAE 9254.

Development of Fire-resistant Steel Structural at Durgapur Steel Plant

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In view of the growing requirement for steel structures in the country, demand for fire resistant steel (FRS) has increased. At present, fire protection of steel structures is being met through other means, like fire protection coating, fire resistant packing, etc. which are very costly options and require regular maintenance. At high temperatures, both the flexural strength and tensile strength of steel decrease as does the modulus of elasticity. To meet the growing demand of fire-resistant steel, SAIL has recently developed FRS in WPB and NPB sections as per IS 15103:2002 specification. One Cr-Mo based fire-resistant steel (FRS) heat was made at DSP through BOF-LF-BRC route. Blooms were successfully rolled into two sections namely, WPB-160 and NPB-250 structural. The room temperature and high temperature (600 ^{o}C) tensile properties of FRS met all the requirements of IS 15103:2002 standard. This steel is characterized by its ability to retain two-thirds of its specified room temperature yield strength when tested at 600 °C. Performance evaluation of FRS and plain carbon steel structural was carried out under simulated fire condition at CSIR-CBRI, Roorkee. In three-side fire exposure of beams under load, the FRS structural exhibited almost two times superior performance than plain carbon steel under standard fire exposure (as specified in IS: 3614 (Part 2) – 1992, BS: 476 (Parts 20 & 22) – 1987 and ASTM E 119). In column condition under four-side fire exposure, the FRS was found to endure 1.5 times longer duration than plain carbon steel in attaining critical temperature for failure. Based on these studies, CSIR-CBRI, Roorkee has issued the performance certificate for use of FRS structural from SAIL in construction segment. With this development, SAIL has established the requisite process technology for producing FRS structural and is in a position to commercially supply different sections as per the market requirements.

Synergistic Effect of Alloy Design and Hot Rolling Parameters on Enhancing DWTT Properties of X70 Line Pipe Steel

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This paper reports on the experience with hot rolled coil production of X-70 line pipe steel in 12.4 mm with drop weight tear properties at -30 °C. A correlation of steel micro-structure with drop weight properties along the hot rolled coil length was established with the process parameters. A typical combination of acicular ferrite and polygonal ferrite was targeted for achieving the strength, toughness and drop weight properties. Formation of this microstructure was possible by controlled parameters which include slab reheating for homogenous steel structure, recrystallization control rolling during roughing, control of bar temperature for proper finish rolling for austenite conditioning and accelerated cooling to attain desired structure. Although all the rolling conditions were stretched within the hot strip mill capability, an alloy system was critically designed so that the hot rolling temperature regime that could be conveniently maintained in the hot strip mill. This had resulted to achieve desired microstructure with combination of polygonal ferrite, acicular ferrite with some bainitic ferrite that would be beneficial for achieving the DWTT toughness at -30 °C for thicknesses up to 12.4 mm. The successful commercial production was put in place with the back of successful in plant trials.

Keywords: X70 pipeline, DWTT toughness, microstructure, controlled rolling.

Next Generation Ultra High Strength Hot Forming Steel

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Ultra-High Strength hot forming grade steel in automobile body structure gives cost-effective lightweight structure with passenger's safety. Boron added steels are heated to the austenitizing

temperature and after hot forming and die quenching it transforms into martensite structure. Typical 22MnB5 steel after hot forming archives the tensile strength about 1500 MPa with 5% total elongation. Further strengthening of hot forming steel requires hardening of its martensite phase by addition of carbon and other alloys. A combination of grain refinement, hardenability and precipitates has been studied and a leaner alloy and process parameters design was done to achieve tensile strength more than 2000 MPa maintaining the required ductility.
Manufacturing process of hot forming was simulated in laboratory to obtain flatbed die quenched samples. The hardness and microstructure the hot rolled samples contain low carbon ferrite pearlite structure. The transformation temperature (Ac3 ~800 ^{o}C) was obtained by dilatometric analysis in Gleeble 3085. The hot formed samples were tested for its hardness and tensile properties as per ASTM-E8 sub-sized tensile specimen (gauge length 25 mm). SEM, TEM and XRD of hot formed specimen were studied to obtain the microstructure-property correlation. Hardened martensitic structure with about ~2% retained austenite has improved the strength and ductility of the hot formed steel.
Hot formed steel of tensile strength of 2000 MPa and 7% elongation has been successfully developed in laboratory with low C (<0.32 wt.%). The oxide layer formation during heating was found significantly low in this steel due to its lower Ac3 temperature. This uncoated martensitic steel has been found suitable for hot forming application of critical automotive components.

Effect of Composition and Microstructure on Fracture Toughness of Hot Rolled High Strength Steels

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Fracture toughness is an important parameter for the performance evaluation of different materials used in critical applications such as line-pipe steels, used in the transportation of oil and gas over long distances. However, due to the high ductility of such steel, the crack tip opening displacement (CTOD) is a widely used technique to estimate the fracture toughness, instead of the plain strain fracture toughness (K_{IC}). In the present study, the fracture toughness evaluation has been examined in a hot rolled microalloyed steel grade, S700MC along with two API X70 line pipe steel grades Cr-Nb based and Ni-Nb based grades. The CTOD values of S700MC grade is significantly lower as compared to both the X70 line pipe steels. The microstructural characterization of the steels was carried out using an optical microscope, scanning electron microscope (SEM) and electron back-scattered diffraction (EBSD). While the line-pipe steel has bainite as a major phase in the microstructure, the S700MC steel has primarily ferritic microstructure with interphase carbide precipitates. The fractographs of the line pipe steel showed completely ductile features while it was a mixed mode type failure in the case of S700MC. The present study summarizes the effects

of chemistry and hot rolling process on the microstructure on the mechanical properties and fracture toughness of the steel.

Development of SAE9254 Wire Rods for Suspension Spring Processing Through Induction Heating and Water Quenching Process

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Suspension and coil springs for automotive application are normally heat treated through austenitizing followed by oil quenching and tempering. Hardening through water quenching followed by tempering is a new technique companies have developed in recent years. Few Indian companies are pioneer in this and Indian steel manufacturers also coming up to meet the product requirements for supplying as rolled steel replacing imported steel. The as rolled product need to be free from hard inclusions like Alumina and surface quality must be flawless to meet desired fatigue properties of the final spring product in application. In steel making process this requirement is achieved by adopting clean steel technology. Restriction in Al addition and judicious selection of ferro alloys as well as casting powder, tundish covering compound etc., is important to achieve success. Low S input to secondary refining, removal of initial slag followed by addition of SiO_2 based synthetic slag is key to maintain V ratio near 1, which pushes inclusion composition towards SiO_2 corner in ternary diagram. The thickness of inclusions are extremely important and non-deformable inclusions, thickness >10 micron is detrimental towards spring performance. To eliminate minute of surface flaw in as cast product, grinding for all 4 faces and corners are essential followed by hot rolling with good roll pass condition. Depletion of carbon is an important aspect ensured strict temperature as well as atmospheric control inside reheating furnace. Post rolling treatment is provided to ensure softer structure as possible to facilitate drawing. Some customers go for patenting to eliminate microstructural non-uniformity generated during hot rolling process.

Establishing Processing-microstructure-texture-mechanical Behaviour Paradigm in DP600 Steel

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Dual phase steels offer a simple two phase microstructure comprising of soft and ductile ferrite phase and hard and brittle martensite phase that can be tuned to achieve optimum stress and strain partitioning between the two phases to achieve not just the desired strength-ductility-toughness combination but also excellent formability. In the present investigation, we perform two thermomechanical treatments on DP600 steel to achieve different volume fractions of the martensite phase and strength of texture to study the effect of microstructure, texture resulting from different processing routes on the mechanical properties with particular emphasis on relatively high toughness at lower strain of around 10% for automotive applications. It was observed that the initial ferrite pearlite microstructure of DP600 steel was fragmented after rolling reduction with the 75% rolled sample showing a stronger gamma fibre than the 50% rolled sample. On intercritical annealing, the ferrite pearlite microstructure transformed to ferrite martensite microstructure with higher volume fraction of martensite in the 75% rolled sample (49.4% versus 45.5%) which also showed weaker gamma fibre indicating complete recrystallization of the ferrite phase. Tensile tests of the cold rolled and intercritical annealed samples showed an increase in yield and tensile strength with similar ductility with increase in rolling reduction. For the intercritical annealed samples, the 50% rolled and annealed samples showed higher strength (yield strength of 551 versus 375 MPa) without significant decrease in strain hardening ability (tensile strength to yield strength ratio decreasing from 1.8 to 1.5) contributing to sufficient ductility (14% from 26%) compared to the 75% rolled samples despite lower fraction of the martensite phase. Microstructural analysis using electron back scatter diffraction indicates optimum stress and strain partitioning between the two phases for the 50% rolled and intercritical annealed samples that contributes to higher strength with sufficient strain hardening. Nano hardness within the ferrite and martensite phase obtained from grid indentation experiments clearly indicate that reducing the difference in hardness of the two phases results in achieving optimum combination of strength and strain hardening providing higher toughness at 10% strain (75 MJ/m^3 vs. 59 MJ/m^3) for 50% rolled and intercritical annealed sample than 75% rolled and intercritical annealed sample, thus manifesting a unique strategy to achieve microstructural engineering in DP600 steels.

Bridging Microstructure and Crystallography with the Micromechanics of Cleavage Fracture in a Lamellar Pearlitic Steel

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The present study focuses on the microstructure-based cleavage crack propagation in a Charpy impact tested fully pearlitic steel by correlating microstructure and crystallography with the overall fracture behaviour. The importance of pearlite lamellae orientation in providing preferred fracture paths is discussed, encompassing the mechanism of interface decohesion and stepwise crack propagation through a mathematical model simulation. While the {100} cleavage cracking is well familiar in pearlitic steels, crack propagation along the {110} crystallographic planes can also prevail in some pearlite colonies or nodules. This is related to suppressing the crack tip dislocation emissions due to restricted slip transferability across the lamellae interfaces. Besides, the strain incompatibility due to large elastic modulus or Schmid factor mismatch across the pearlite nodule boundaries is responsible for triggering internodular cracking in the steel. Connecting the framework of fracture mechanics with the experimental observations, the mechanisms pertaining to different types of tear ridges formed within a pearlite colony are proposed. This certainly illuminates the role of lamellae orientation in the process of crystal bending and shearing at the tear ridges formed within the colonies or at the twist nodule boundaries.

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Study on Cold Formability of beta Titanium Alloy

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Beta titanium alloys are the most versatile class of titanium alloys as they offer the highest strength to weight ratio and very attractive combinations of strength, toughness, fatigue and corrosion resistance. Very high strength levels (up to 1300 MPa) can be achieved by tailoring the extent of mechanical working and heat treatment cycles.

Ti15V3Cr3Sn3Al alloy, also designated as Ti-15-3-3, is a meta-stable beta alloy having good cold formability and attains very high strength by proper selection of cold working, solution treatment and aging cycle. The alloy is well identified material for light weight structures and propellant/pressurization gas storage tanks for Aerospace applications. Near-net shaped components can be realized with good surface finish which sometimes may call for minor skin machining.

Deep drawing trials were attempted on 5mm thick annealed Ti-15-3-3 alloy sheet using in-house 1000T hydraulic press facility. Necessary dies and tooling which includes top punch, bottom die and blank holder were fabricated for carrying out deep drawing trials. 200 mm dia. domes were realized which were characterized w.r.t. dimensions, tensile properties and microstructural analysis identified from top and bottom location of the dome. Also, 5 mm thick sheet was taken-up for roll bending trials to realize 200 mm dia. cylinder of 50 mm height. Samples were identified for detailed characterization at 120° apart circumferentially.

The present paper brings out the details of deep drawing and roll bending trials performed on Ti-15-3-3 sheets and results of the subsequent analysis on the formed dome and cylindrical part.

Development of Dump Mesh Component for Missile Applications using PBF based 3D Printing Technology

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A propulsion system based on SFDR (Solid Fuel Ducted Ramjet) technology is being developed by DRDL, Hyderabad which is crucial for the indigenous development of long-range air-to-air missiles. The propulsion unit consists of a dump mesh component, a grid type of structure that is structurally assembled to the combustion chamber to allow passage of ambient air into the chamber which aids in Stage-II combustion process. The component consists of aerodynamically shaped multiple channels which are deep through the thickness. Currently this component is being manufactured by CNC machining process from a Maraging Steel block, which requires exhaustive tooling and machining resulting in long production lead times and also high rejections. The component has been taken up for development through 3D printing technology using Powder Bed Fusion (PBF) process, which has potential to build intricate designs and also at reduced lead times.

Initially, a section of the component along with test specimens were 3D printed in Maraging steel. The 3D printed component section and test specimens were analysed for chemical composition, density and internal porosity, microstructure, dimensional accuracy and tensile properties. Radiography analysis has revealed presence of layered defects in the vertical and inclined built specimens resulting in lower density (~98%) builds. Dimensional inspection and analysis were also carried out by laser CMM which has shown a distortion of ~0.5 mm in the middle region of the component. To overcome these deviations, the process parameters were modified, introduced additional supports along with stress-relief treatment step, and a full-sized Dump mesh component was 3D printed in the next iteration. The initial evaluation of component revealed density to be >99.6% and a distortion of <0.2 mm in the middle region, which confirms to the design requirements. Microstructural characterization for phase analysis and tensile property evaluation are in progress. Rig testing is being planned to be carried out at DRDL to evaluate the performance of the component.

Fig. 1. 3D Printed Dump Mesh component of size 260 x 110 x 35 mm.

Influence of Processing Parameters on Formability Characteristics of Cold Rolled and Annealed Extra Deep Drawing Steel Sheet

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In the light of several regulatory frameworks on greenhouse emission and road safety, the automotive industry prefers to make use of steels having a combination of strength, ductility and its ability to be engineered in a variety of ways. In the recent years low and ultra-low carbon steels like extra deep drawing aluminium-killed, interstitial free, interstitial free high strength steels are extensively used for the auto bodies because of their superior formability. Though the aluminium-killed Extra Deep Drawing (EDD) steel sheets are extensively used for stringent forming applications, there is still scope for substantial improvement with regard to its formability properties like total elongation percentage, plastic strain ratio (r-bar) and strain hardening exponent (n).

An attempt has been made to understand the microstructure developed during annealing of the cold rolled EDD steel by varying process parameters and study the morphology and particle size distribution of aluminium nitride precipitates. The hot rolled steel sheets of EDD steels with and without Ti addition have been used for the studies. The hot rolled sheets were cold rolled in experimental cold rolling mill with varying 65% and 75% reductions and the annealing was carried out in thermo mechanical simulator and muffle furnace. The total elongation percentage and the average plastic anisotropy ratio of cold rolled and annealed EDD steels sheets have been observed to increase substantially to 44% and 1.69 respectively, which may primarily be attributed to gamma texture in the cold rolled, annealed and skin passed sheets as a result of titanium addition and two stage annealing.

The final microstructure depends on the initial grain size formed during the reheating of steel before hot rolling. Large austenite grains were formed with increase reheating temperature. The minimum energy needed for atoms to diffuse to obtain a more stable state is smaller which increases the grain boundaries migration and grains continue to grow at higher temperatures.

The forming properties of EDD steels are influenced by the volume fraction of grains with ND//<111> texture component. Steel 1 was observed to possess a very weak ND//<111> texture component whereas Steel 2 with a very strong intensity of the ND//<111> texture component for a cold reduction of 75% which is more favourable for superior forming characteristics.

Hot Deformation Studies of Non-Oriented Electrical Steel Through Gleeble

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During the hot rolling of silicon alloyed non-oriented electrical grade steels, the shifting of the materials between the stands as the mill load increases resulted in a poor quality of the rolled product and productivity. An understanding the deformation behaviour with the mill load was expected to overcome the quality and productivity issues. Hot deformation studies involving uniaxial deformation was carried out using Gleeble-3800C thermo-mechanical physical simulation system on two typical electrical steel grades, with Si contents at 0.5% and 0.7%. The deformation temperature varied from 800 °C to 1050 °C at an interval of 25 °C, the strain rate was varied (1, 5, 10, 25, 50 and 100/sec), while the strain was maintained at a constant at 0.5. The flow stress values obtained revealed that the predominant softening mechanism was dynamic recovery, at lower temperature and high strain rate of the order of 100/sec, where high stress value was observed. At the initial state at the start of the hot rolling, the microstructure of the steel was in the two-phase region ($\alpha+\gamma$). With fall in temperature during rolling the microstructure transforms to a fully ferritic rolling at the finish rolling stage. On the basis of a detailed flow stress study, the deformation temperature was preferred below 900 °C for 0.5% Si and 950 °C for 0.7% Si electrical steel. At these temperatures, the steel has lower flow stress, which ensures the ease of material flow associated with plastic deformation. The phase analysis of the steel was assessed using the FACTSAGE software and the metal flow curves were assessed using JMatPro software. The material shifting of material that occurred with higher work hardening of the steel could be eliminated, when the plastic flow regime was maintained in a range between 900 °C and lower flow strength of the steel. The hot deformation temperature range was established based on the Fe-Si phase diagram.

Keywords: Electrical steel grades, Hot deformation, Hot rolling, Compression testing and Flow stress

Effects of Multiscale Porosity and Pore Interconnectivity on *in vitro* and *in vivo* Degradation and Biocompatibility of Fe-Mn-Cu Scaffold

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Iron (Fe) based scaffolds are promising candidates as degradable metallic scaffolds. High strength and ability to control the degradation with tailormade composition and porosity are specific advantages of these scaffolds. In this research work, iron-manganese-copper (Fe-Mn-Cu) based scaffolds, with multiscale porosity, are developed through powder metallurgy route using naphthalene as spacer material. Porosity in the scaffolds ranged from 42-76%, where majority of the macro-pores (≥20 µm) form interconnected channel network. XRD analysis confirms the presence of MRI compatible and antiferromagnetic austenite as major phase in all the scaffolds. Developed scaffolds in this study have minimum ultimate compressive strength of 7.21 MPa (for 30 Naph), which lies within the range of human cancellous bone UCS (2–12 MPa). Degradation rates of the scaffolds are determined from static immersion test, where scaffold with highest porosity (76%) shows highest degradation rate of 2.71 mmpy when immersed in Hank's balanced salt solution (HBSS) at 37°C for 30 days. Increased degradation rate of the scaffolds has no cytotoxic effects on MG63 cells as studied by alamar blue assay and live/dead imaging. When implanted in rabbit femur, scaffold with higher porosity showed enhanced osteogenesis, as evident through micro-CT and histological analysis. It is hypothesized that presence of multiscale porosity with high degree of interconnectivity facilitated the better bone regeneration within and around the Fe-Mn-Cu scaffolds.

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Effect of Aging Temperatures on Pitting Corrosion Behaviour of Hot Rolled High Nitrogen High Manganese Austenitic Stainless Steels in Natural Seawater Condition

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In the present work, hot rolled High Nitrogen high manganese austenitic Stainless Steels (HNSS) were solution annealed and aged at 700 °C, 800 °C and 900 °C for 14 hours. Precipitation kinetics at the Grain Boundaries (GB) of HNSS was studied using TC- PRISMA simulation and SEM analysis. Pitting corrosion behaviour of HNSS at solution annealed and aged conditions were studied using anodic polarization and Electrochemical Impedance Spectroscopy (EIS) analysis. TC-PRISMA simulation results showed that equal volume fraction of chromium nitride (Cr_2N) precipitates was observed in grain GBs of austenite in all three aging conditions. However, large size precipitates were observed in samples aged at 900 °C compared to samples aged at 700 °C and 800 °C. SEM investigations showed the presence of lamellar Cr_2N at the GBs and coarse lamellar austenite in regions adjoining the GBs in samples aged at 700 °C aging temperature. Disc type Cr_2N precipitates were observed in GBs of austenite in 900 °C aging temperature. Besides, sample aged at 900 °C exhibited relatively stable and homogenous layer compared to solution annealed and samples aged at 700 °C and 800 °C.

Deformation Behaviour of EN25B Forged Steels: Effect of Non-metallic Inclusions

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The article presents a thermomechanical simulation of EN25B steel (European grade Ni, Cr steel). The evolution of stress stain curves and their correlation with inclusion evolution at various strain rates and temperatures up to 50% deformation is studied using a Gleeble simulator 3800. A processing map is developed based on simulated Gleeble data in a two-dimensional space of strain rate and temperature. A safe plastic deformation regime is identified based on developed processing maps. The safe deformation zone lies in the high temperature and high strain rates regime, irrespective of true strain value.

At lower true strain value, the instability regime locates at lower strain rates and lower temperature and extends to higher temperature with a decrease in strain rates. At a higher true strain value of 0.6, the instability regime locates at higher strain rates and lower temperatures and extends to higher temperatures with increased strain rates.

A higher volume fraction of dynamically recrystallized grains was estimated in a safe regime with higher strain rates and temperatures. No recrystallization was observed at 850 °C, irrespective of strain rates. Inclusions were modified to calcium oxy-sulfide after calcium injection. No cracks were identified around inclusions in the experimental range of strain rates and temperatures up to 50% deformation.

The instability region indicating flow localization could not be attributed to the presence of inclusion and crack generation. A more detailed microstructure analysis would be required to explain the regime of instability.

Keywords: EN25B steel, Non-metallic inclusions, Gleeble simulation, Cracks, Processing maps.

COLORS of SCALE: A Fundamental Study of Black and Red Scale Defect in Hot Rolled Products

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A detailed investigation was carried out to understand the chronic issue of Red and Black coloured scales on the hot rolled coils. A comparative study has been done on un-affected and, affected regions of the coils to understand the differentiating features of the defect region. Further, a correlation of the characteristic features of both black and red scales with processing condition has been presented. Average slab drop out temperature was lower and finish rolling temperature was higher for hot rolled sheet having Red scale defect in comparison to the sheets having Black scale defects. Average scale thickness was marginally higher in Red scale compared to that of Black

scale. Adherence of Red scale was poor compared to that of black scale making it easier to pickle. Scale layer composition was similar in both the defects. However, in top layer hematite seems to be more prominent in Red scale defect. Scale at 1000 ℃ contains- FeO, Fe_3O_4 and Fe_2O_3 in the ratio of 95: 4: 1. Remnant scale after descaling leads to its fragmentation exposing it to excess amount of oxygen. This in turn causes transformation of FeO directly to red Fe_2O_3 making scale appear red. This study and corresponding document provide guidance for all defect investigations directly or indirectly related to hot rolled scale. It is expected to improve collective understanding about scale, reduce defect investigation time and as a result, will speed up the decision-making process to eliminate the defects.

Keywords: Red scale, Black scale, Hot rolling, Wustite, Magnetite, Hematite.

Approach to Develop End to End Solution in API X70 Grade Line Pipe Steel

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The oil and gas transportation projects are often very complex involving the variability at steel mills, plate makers, transportation, final erecting and site commissioning. The requirements for line pipe steel can be over and above the stated standards, where crucial metallurgical and mechanical aspects play the vital role. The new TMCP rolling concepts of steel not only improve mechanical properties and toughness but it also extends its blueprint in welding, corrosion and wear aspects based on the project requirements.

An approach is captured in the present paper wherein enhancement of steel design aspects is looked into to cater the needs to the client requirements and support the long life of the pipeline. Accomplishing the preliminary criteria of mechanical properties and toughness an architectural innovation is carried out in X70 grade TMCP rolling. The target microstructure of ultra-fine grains with mainly acicular ferrite structure is achieved by controlling the flow stress in each rolling pass and avoiding the partial recrystallization. The chemistry design is done to meet required weldability and good erosion-corrosion life of steel along with cost efficient product design. Successful implementation of newly designed API X70 grade is done in NRL project of PNCPL (Paradip Numaligarh Crude Oil Pipe Line Project).

Cost effective Process Route for Development of 430 Ferritic Stainless Steel

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Ferritic stainless steel having low alloy addition and high chromium (16-18%) content such as Grade 430 has a huge market prospective in architectural, automotive parts, fasteners, oil burners parts, television cones, machinery parts application. This grade is known for its moderate temperature corrosion resistance as well as higher surface glossiness.

In this study, an attempt has been made to develop a high strength, moderately acid resistant white metal for usage in Food grade application through a cost optimization route. The favorable cast structure was achieved with increased equi-axed grains percentage by usage of Electro-magnetic stirring during casting. Hot rolled pickled coils were directly taken for heavy cold reduction in 20-Hi Sendzimir Mill (Z-mill) without intermediate annealing in batch process bell type furnace. Final annealing was carried out at horizontal continuous annealing having reducing atmosphere to obtain uniform re-crystallized grains.

Final product was analyzed for mechanical properties (Yield strength, Ultimate Tensile strength, % Elongation, Hardness) using Shimadzu AGS-X 100KN Universal Testing Machine. Ridging values were analyzed with 20% Elongation in rolling direction using Mitutoyo SJ 210 surface roughness tester. Erichsen cupping test was carried out to verify the formability and ductility of the material. Microstructure of the developed product was analyzed for phase and grain size using Optika-B600 Italy make microscope. Glossiness was measured using German make Elcometer 408.

Keywords: Ferritic stainless steel, Glossiness, Equiaxed structure, Batch Annealing Furnace, Continuous Annealing, Ridging, Erichsen cupping.

Microstructure and Mechanical Properties of Additively Manufactured Al20X with Different Heat Treatments

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Al20X™ is among the strongest commercially available additive manufactured aluminium alloys with yield strength of nearly 450 MPa having a 12-15% ductility, at room temperature. The high strength Al-Cu-Ag-Mg alloy comprises TiB_2 particles which enables the successful fabrication of dense parts using the laser powder bed fusion process and hence offers the ability to potentially use this alloy at temperatures beyond other aluminium alloys. This study involves a detailed characterization of the as printed Al20X alloy and establishing a heat treatment window that ensures thermal stability of the microstructure, as a prelude to evaluating the creep behaviour of the high strength Al alloy. Detailed characterization for porosity, microstructure, tensile behaviour of the alloy in the as printed and heat-treated condition is presented in this study.

Effect of Purging Gas on Ambient and Cryogenic Properties of AISI 321 Weldments

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Industrial manufacturing involves a vast number of tubular weldments, often of very small diameters. The quality of these joints is critical for the efficient operation of systems, especially in strategic areas such as the aerospace, defence and nuclear industries. Gas tungsten arc welding (GTAW) is usually preferred and widely used for such activities due to its appreciable process control that results in high-quality, clean weld in similar as well as dissimilar welding.
During welding, it is essential that the atmosphere be carefully controlled to prevent any undue corrosion. The extreme heat produced during welding can cause the metal to oxidise by reacting with atmospheric oxygen resulting in a softer weld bead of poor appearance and possible cracks.

To prevent this, inert gases such as helium, argon, or a mixture of these two are purged through tubes at an optimal flow rate during welding.
Stainless steels are among the most common materials used for industrial tubular applications. Oxygen contamination in stainless steels due to insufficient purging is known as 'sugaring' or 'dross'. Such weldments of austenitic stainless steel are increasingly subjected to cryogenic temperatures in aerospace applications. However, the effects of sugaring or dross on the mechanical properties at cryogenic temperatures have not been explored to date. This novel study, therefore, investigates the influence of the purging gas flow rate on AISI 321 weldments and the effect of sugaring on the cryogenic mechanical properties for the first time. Welding trials were performed on tubes of 1 mm thickness with nominal, reduced, and no purging. The welds were evaluated by visual inspection and non-destructive testing. Furthermore, mechanical property evaluation was carried out at ambient and cryogenic temperatures. The variations in yield strength, ultimate tensile load and elongation were compared and correlated to the effects of corrosion at both conditions, providing necessary insights into purging requirements for space applications.

Keywords: GTA welding, Austenitic Stainless steel, Sugaring, Purging gas.

Development of High Strength Weather-resistant Cold Rolled Coils for Solar Photovoltaic Panel Application

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SAILCOR is a weather-resistant structural steel grade produced in form of hot rolled (HR) and cold rolled (CR) coils at Bokaro Steel Plant (BSL) of SAIL. In order to explore the usage of this special grade of steel in solar power industry for manufacture of supporting steel structures like columns, rafters and bracings of solar photovoltaic power panels, with enhanced property requirement of yield strength (YS) ≥ 350 MPa and total elongation of 20% minimum, the development of customized SAILCOR grade CR coils was undertaken at BSL. Trial heats of 300 tonnes were made through BOF-LF-CC route and the as-cast slabs were hot rolled and processed into 3.4 mm (thickness) x 1280 mm (width) HR coils in Hot Strip Mill (HSM). The HR coils were subsequently pickled and cold rolled to 1.6 mm (thickness) x 1252 mm (width) CR coils in Tandem Cold Rolling Mill-I (CRM-I) followed by batch annealing under protective

hydrogen atmosphere using specially designed annealing cycle. The corrosion performance of the customized variant of weather resistant SAILCOR grade steel was evaluated comprehensively through standardized corrosion testing procedures involving anodic polarization, salt fog and atmospheric corrosion testing and compared with IS 2062 E250BR+Cu and IS 2062 E250BR steels of equivalent yield strength. Under anodic polarization testing in 3.5% sodium chloride (NaCl) solution, the customized SAILCOR grade steel was found to exhibit 4 times superior corrosion resistance over IS 2062 E250BR grade of steel. The customized variant of SAILCOR steel also showed marked reduction in loss of thickness owing to corrosion penetration, sluggish corrosion kinetics and impeding of corrosion rates vis-à-vis IS 2062 E250BR+Cu and IS 2062 E250BR steels over prolonged exposures comprising more than 7 months of atmospheric outdoor exposure testing conducted as per ASTM G50 and over 3 months of 5% NaCl salt fog exposure testing conducted as per ASTM B117.

Yield Improvement of Investment Casting through Optimization of Gating and Risering System for Aerospace Applications

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Investment casting process, also known as “Lost Wax” process is widely used for the realization of aerospace components due to better dimensional accuracy and good surface finish. Proper metal feeding and gating system plays a significant role in realization of quality castings. Optimization of the gating system through trial and error method in the shop floor is cumbersome and largely increase the lead time and cost. With the advancement of computing technology and simulation process, casting simulations are widely used in the modern foundries to predict and eliminate casting related defects. In comparison to shop floor trials, it is fast and more cost effective, which added to its popularity and wide usage.

Development of turbo pump casting for aerospace application is a challenging task due to its intricate geometry with volute profile and large thickness variations. In this work, Procast simulation software methodology is adopted for optimizing the gating system for development and realization of the aerospace quality investment casting.

The casting model was simulated to identify hotspot locations using the thermal module and probable casting related defects. Based on the results, proper feeding and risering system was optimized with bottom pouring to avoid turbulence and fins on the low thickness volute regions of the casting for directional solidification. The casting was successfully realized using optimized gating and risering system. The casting was subjected to 100% radiography and dye penetrant testing to ascertain the quality of the casting. The result shows that casting defects were reduced to a large extent and are within the acceptable limit as per specification. Thus, rejection levels are much decreased and the yield is significantly improved. This paper explains the methodology adopted and all the iterations done for realizing aerospace quality investment casting using optimized gating and risering systems.

Keywords: Investment casting, ProCAST, Gating system, Optimization, Hot spots, Niyama.

Metallurgical, Technological and Heat Treatment requirement for Wheel Rolling to produce forged Rolled Rail Wheels - A Step towards Atmanirbhar Bharat

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This paper presents latest technological, complex metallurgical and recipe based heat treatment requirement for producing rail wheels of different shapes, sizes and strengths by wheel rolling to cater to present day worldwide requirement of high strength, low weight wheels by railways.
High performance railway networks crisscross the entire globe and are being continually expanded. The trend of today's railway operation is towards higher train speed and increased axle loads. This ever-increasing demand of higher speed calls for keeping the weight of the rail wheels as low as possible and improvement in resistance to increased stresses that result from increasing radial and lateral wheel loads, as well as from increased thermal loads. These exacting requirements can be met only by forged wheels.

For over one and a half century, the Indian Railways (IR) has been the principal mode of transportation in the country. Wheels are the wear parts of the rolling stock and its demand increases with the increase in volume of the traffic.

Presently majority of the forged wheels are being Imported by Indian Railways. A new Forged Wheel plant is being installed in U.P., India. The plant is having a capacity of 100,000 wheels per annum which can be expanded to 200,000 wheels per annum and it will help in Import substitution and will strengthen the concept of "*Atmanirbhar Bharat*".

The state-of-the-art Forged Wheel plant is fully automated with intermediate handling of in process wheels by means of intelligent gantry or by robotic arms. The plant is not only capable of producing wheels as per latest Indian Railways Standards and International Standards but can also be used for developing new Wheel designs with respect to contour and metallurgical properties.

Effect of Scanning Speed on Eddy Current Inspection of 304L Tubes

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Eddy current testing (ECT) is one of the non-destructive testing techniques widely used for inspecting the austenitic stainless steels tubes. This testing is capable of detecting the surface and sub-surface flaws, for sorting materials, to measure thin wall and coatings. In this paper focus is given in study the effect of scanning speed while inspecting stainless steel tubes with a fixed equipment setting. Results shows that sensitivity of eddy current inspection method is directly related to the scanning speed which in turn depends on the frequency response and filtering setting of the equipment. To achieve the best sensitivity, scanning speed shall be optimized with equipment settings.

Keywords: Non-destructive testing, Eddy current, Scanning speed, 304L.

Fatigue and Pitting Failure of Blast Furnace Skip Winch Gear

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Failure analysis of skip winch gear was investigated in order to find the root cause and means of overcoming them in the future. The material grade of the gear is 20CrMnMo4 and it has failed within 5 years of service which resulted in forced shutdown of blast furnace for nearly 14 hr and created huge impact on iron production. The failure was investigated with respect to steel grade, metallurgical and mechanical properties. From the visual observation, fatigue striations and pitting were found. The type of pitting observed was dedendum pitting which occurs when loads are at or close to maximum allowable surface loading values. The dedendums are most vulnerable to failure, because of the preferential orientation of the surface micro cracks along the tooth profile. Low hardness of 51.5 HRC on the surface against the ISO 6336 specification of 58 HRC required for the industrial gear was the root cause for the dedendum pitting. Along with pitting, minor cracks and fatigue striations were also observed by SEM. The gear failure has occurred due to mixed mode mechanism of pitting, micro cracks and fatigue. Fatigue was initiated by pitting associated with micro cracks which acted as a stress raiser. The solution is to select material with surface hardness greater than 58 HRC in future.

Keywords: low hardness, dedendum pitting, micro cracks, fatigue.

Development of Wire Rods for Higher Torsion & Reverse Bend Properties in Motor Tyre Bead Wires

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Motor Tyre Bead (MTB) wires (are used in automotive tyres to hold the tyre with the wheel-rim. These are high strength wires coated with copper and tin which provides good adhesion with rubber compound of the tyre. The bead wires are stranded before putting in tyre hence need to have higher torsional properties. High carbon grade (0.81/0.85% C) wire rod has been developed with enhanced strength and ductility for tyre bead application to ensure the direct-drawn wire sustains more number of twists before failure during torsion testing. Ultra clean steel is used for optimised continuous casting process of 165 mm x 165 mm billets whereas during rolling, wire rod needs to have excellent surface properties as the surface defects act as initiation site for breakages. The rolling temperature and Stelmor cooling are controlled to achieve fine pearlitic microstructure with low interlamellar spacing so that the material can have higher strength and superior wire-drawability in direct drawing process without intermediate lead patenting. The improved properties of the wire rod helped in increasing the torsion strength from 30 min to over 40 twists before failure. Better ductility also helps in higher values during Reverse Bend Test (in which repeated bending of the wire is done through 90 ° in opposite directions). Along with the torsional strength, the wires should have higher breaking load (430 kg minimum), for which the rod chemistry and cooling during rolling process were optimised accordingly to achieve desired high strength and ductility.

Keywords: Motor Tyre Bead, Direct Drawn Wire, Torsion Testing, Reverse Bend, Breaking Load.

POSTER PRESENTATIONS

Development of Lean Alloyed TRIP Aided Bainitic Advanced High Strength Steel

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The advent of bainitic AHSS with TRIP effect has given a good combination of strength and ductility. A low carbon lean alloyed steel with Ti and Nb microalloying has been optimized to attain the product of tensile strength and ductility greater than 20 GPa with a bainitic microstructure. The steel was subjected to inter critical annealing in the temperature range of 790 to 830 ^{o}C at two different holding times followed by austempering heat treatment in the temperature range of 250 to 450 ^{o}C at two different holding times. The microstructures obtained consisted of a bainitic ferrite, in a matrix of polygonal ferrite along with retained austenite and martensite. The T_0 and T_0' temperature was evaluated and the maximum volume fraction of bainite at the chosen austempering treatment was assessed from the phase diagram made through thermocalc software. Under several conditions the desired properties were achieved with best properties of 1022 MPa tensile strength and 25% E. The microstructure evolution and the mechanical properties of the steel at the various processing conditions are discussed. The steel processed can be manufactured in the line by maintaining the coil holding temperature in the bainitic temperature regime. The properties developed in the present study compares well with commercialized TRIP steels. The steels with such high strength and ductility can be promoted for use in automotive structural safety components while reducing the weight of the components for fuel efficiency and CO_2 emission.

Keywords: Bainitic Steel, TRIP Steel, Third generation steel, Microstructure, and Mechanical properties.

Development of Fe 550 SD at NBM from Quench and Tempered Route

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Tata Steel was producing Fe500SD grade rebar (~130 kt/month) for retail segment, for almost more than a decade (from 2005 to May 2021). Hence, to create a product differentiator in the market, there was a need to launch a new and better product than competitor's product. M&S envisaged a PAN India migration from Fe500SD to Fe550SD grade for entire retail segment. This initiated the process of NPD in all mills of Tata Steel.
New Bar Mill being the largest volume producer of 10, 12 and 16 mm rebars which go to retail market (~2/3rd of total retail volume), the first priority was to develop Fe 550SD from this mill. Also, being the fastest mill and originally designed for producing Fe 415 grade, challenges to produce higher strength & higher ductility rebar i.e. yield strength ≥ 550 along with Elongation ≥14.5% and UTS/YS ratio ≥1.15; was more in NBM.
To achieve the combination of high strength and high ductility, optimum rim fraction and core strengthening is required. YS is majorly a function of rim thickness/fraction while UTS majorly depends on core strength. Optimum Mn addition to increase the hardenability and pearlite fraction and addition of Si to increase the ferrite strength was explored, thus increasing the core strength. Cost impact of these elements is lower than other strengthening elements (CE max - 0.61).
After successful trials (with the suitable range of billet chemistry and correct water quenching parameters in sizes 10-16 mm at NBM, it was proposed to launch this product in retail with full basket of retail (8-32 mm). Hence trials were taken in other mills of Tata Steel and trials were successful. The product is developed, and commercial production started from June 2021 onwards.

Studies on Correlation of Microstructural Morphology on Corrosion Behaviour of Spring Steel Grades SUP9 and SUP11A

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Spring steels are widely used in automobile industries for suspension system due to its good strength and fatigue resistance. Spring steels grades (SUP9 and SUP11A) produced through conventional BOF route, continuous casted and hot rolled in Visakhapatnam steel plant were chosen for investigation. Both SUP9, SUP11A grades fall under high carbon steel grades with carbon content of 0.6% and silicon content of around 0.3% and only difference between two grades in composition is SUP11A has boron up to 0.003% which increases its hardenability during heat treatment. Corrosion plays an important role in determining the service life of the suspension system in automotive applications due to their in-service conditions like dust, mud, stagnant water etc. In this present work, it is aimed to study the effect of microstructural morphology on the corrosion behaviour of spring steels (SUP9 and SUP11A). Microstructural morphology was observed using optical microscopy and Scanning electron microscopy. Corrosion behaviour were investigated using weight loss measurements and through potentio-dynamic polarization studies using in sodium chloride (NaCl) solution at different concentrations. Consequently, correlation of microstructural morphology on corrosion behaviour of spring steels will be established.

Keywords: Spring steels (SUP9 AND SUP11A), Optical microscopy (OM), Scanning electron microscopy (SEM), Potentio-dynamic polarization and Sodium chloride (NaCl).

Development of Next Generation Hot Rolled Structural Steels

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Hot rolled structural steels are mainly used in infrastructure, construction and general engineering. Usually these grades are easy to produce due to the applicability of wide standard for chemical and mechanical properties. Looking at the present and future user expectations there is a need to develop cost-efficient high-performance steels based on intended application (includes weld-ability, formability, corrosion proofing, fire resistance, fatigue etc.)

Conventional structural steels are made with non TMCP rolling and composition is mainly plain carbon steel. The other properties like weldability, toughness, formability, fire resistance, fatigue and corrosion resistance are not evaluated or guaranteed. This paper aims to explain the TMCP rolling aspects in hot rolling of structural steel (E250 and E350 Grades) in order to get cost efficient, low carbon equivalent steel with fine and uniform grains having superior properties against the conventional steels.
The newly developed structural grades utilises the concept of nano precipitation to drive improved strength with less alloying means less cost, lower carbon equivalent helps to offer improved weldability, higher yield strength offer better rigidity and fatigue aspects, fine and uniform grains offer the toughness, improved fire resistance has been achieved by promoting stable microstructure that decomposes slowly in the event of fire, surface conditions are checked for painting/coating suitability as a corrosion proofing. This paper explains key design aspects in chemistry selection and TMCP rolling to offer the next generation structural steel in Indian Market.

Development of low Cr Ferritic Stainless-Steel Grade with Excellent Toughness and Strength for Structural Applications

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Coated carbon steel with good toughness and strength are traditionally used in the parts for structural applications. However, due to the longevity and lower life cycle cost, there has been a recent effort to replace these with low-cost ferritic stainless steels having similar toughness and strength. This work aims to develop a cost-effective stainless steel as a substitute to carbon steels for structural applications. The main challenges associated with this development are the difficulty in achieving high toughness in ferritic stainless steels, without compromising the strength and cost effectiveness. AISI 409M grade stainless steel was modified in chemistry and batch annealing practices to make it suitable for structural applications. Molybdenum was introduced to impart higher strength and nickel content was increased to achieve both higher strength and toughness. In order to ensure the minimum yield strength requirement of 350 MPa, soaking temperature and soaking time were optimized by extensive lab scale heat treatments. With this modified chemistry and annealing parameters, ferritic stainless-steel material with excellent toughness and a minimum

YS value of 350 MPa could be developed for structural applications as an alternative to carbon steels.

Keywords: structural application, toughness, ferritic stainless steel, batch annealing.

Development of PC300K as Rolled Wire Rod for High Strength LRPC Application

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Lead is used in steel to impart property of high machinability and hence the steels are also called Free Cutting Steels. However, lead fumes are harmful and toxic and can cause significant damage to human health and life when inhaled.
In order to minimize this hazard and threat to human being while manufacturing the steel, the Non-Leaded Free Cutting Steel has been developed jointly by Tata Steel Long Products Limited, R&D of Tata Steel Limited and Technology Group of Tata Steel Limited.
The basic premise is to eliminate lead from the steel and replace it by equivalent proportion of Mn and Cr. The Free Cutting property which is a result of the MnS globules accompanied by Lead would also be replaced by MnS Globules accompanied by Cr.
One heat has been successfully cast in the section 150 x150 mm^2. The macro etch samples were studied for the segregation as well as internal soundness and cast structure properties. The results have been satisfactory and further trials in rolling are in progress in both the wire rods as well as bars.
The challenges in designing, steel making, refining, and casting of the steel have been successfully overcome.
The paper discusses the various steps involved in the manufacturing right from the design stage to the casting stage and the various metallurgical parameters that have considered in the process.
Also, the cross-functional collaborations between R&D, operation and the technical team and functions in developing the chemistry and the technical parameters are also discussed in detail.

Improving Edge Quality of Hot rolled Coils in 11%Cr Dual Phase Ferritic Stainless Steel

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11%Cr-0.02C is a dual phase grade belonging to ferritic stainless-steel group which is widely used in fabrication of railway wagons due to its higher strength to weight ratio and corrosion resistance. It is a sustainable material as after a long service life, there is a very little loss of material due to corrosion. During manufacturing of hot rolled coils from continuous cast slabs, edge cracks were frequently observed thereby leading to unwanted trimming and subsequent yield loss.
In order to minimize this defect, effect of different rolling parameters, like re-heating furnace discharge temperature, mill roll force and strain rate on edge crack was analysed. It was observed that higher roll force and higher draft in each pass was leading to higher strain rate on the material. After studying phase diagram, suitable hot deformation temperature was decided to ensure rolling in austenitic phase. To reduce the strain on material, it was decided to modify the pass schedule at roughing mill. After rolling the material with the suggested changes, edge crack occurrence was minimized in hot rolled coils. It was also observed that the average roll force and draft in each pass of rolling also decreased which resulted in lower strain rate in material. This resulted in reducing wastage of material due to trimming losses thereby improving the yield of the final product.

Keywords: Ferritic Stainless Steel, Edge Crack, Roll Force, Strain Rate.

Influence of Extended Simulation Post Weld Heat Treatment on Steel Micro-structure and Properties of SA738 Gr B Steel Plates

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This paper presents a study made on the response of the steel micro-structure with extended simulation post weld heat treatment (PWHT) and its effect on mechanical properties of SA 738 Gr

B steel plates. The steel plate thickness of 60 mm in quenched and tempered condition was simulated heat treated at 621±10 °C with 6 hr and 12hr soaking time. The mechanical properties viz. strength, toughness and hardness were correlated to micro-structural changes before and after simulation heat treatment. The role of micro-structure was found to be very prominent with tempered bainitic dominance which has difference in behaviour as compared to tempered martensite. The study demonstrates the stability of lath-like bainitic ferrite (BF) is reasonably superior to martensite (M) or tempered martensite (TM) during tempering and simulation PWHT.

Keywords: SA 738 Gr B, tempered bainite, Tempered Martensite, Simulation post weld heat treatment.

Development of 40CrMnMo7 Grade of Tool Steel

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Tool Steel Grade 40CrMnMo7 is widely used in making plastic-moulds and die-boxes. Generally, this steel is used in pre-hardened condition, which enables the customer to directly use the steel by only die-cutting. The particular advantages of this grade of steel is that it saves hardening after the machining. It can be used for very large dimensions in direct supplied condition. The effect of controlled hot rolling of plates, water quenching and tempering operation on the microstructure and hardness has been studied. Tensile strength and toughness properties of 40CrMnMo7 steel was also investigated. In this study, the steel with specified chemistry was made in the BOF and 300 mm thick slabs were produced through continuous casting process. Later the slabs were rolled into 32-150 mm thicknesses in a 4-Hi Reversing Advance Plate Mill at JSPL-Angul through the controlled rolling process. Finally, hardening through optimised water quenching and tempering were performed in heat treatment complex in the plant to achieve the desired hardness level in the final product. In this development, the hardness control in every stage of plate manufacturing process had been investigated. The full hardening and the effects of different tempering temperatures on hardness

had been established after water quenching and normalising process. The hardness values achieved successfully in the specified range 280-340 HB.

Keywords: Tool Steel, Controlled Rolling, Normalising, Quenching, Tempering, Hardness.

Thermal Expansion and Phase Transformation of Medium Mn Steel Studied with in-situ Synchrotron X-ray Diffraction

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Advanced high strength steel having a Mn content of 2 to 12 wt. % show a good combination of strength and ductility owing to their multiphase microstructure. These duplex microstructures (ferrite + austenite) are obtained by either of two ways: 1) heating from the austenitic region and holding in the ferrite-austenite region followed by quenching, 2) heating of an initial martensitic microstructure in the two-phase region and quenching. The exact thermal history has a huge impact on the mechanical properties of Mn steels. However, relatively little is known about relevant structural changes as a function of temperature, such as partitioning of austenite-ferrite and the kinetic behaviour of the related phase transformation. Hence, to ascertain the partitioning and kinetic behaviors, we studied a medium Mn steel (C= 0.18 wt. %, Mn = 5 wt. %) using high-temperature in-situ synchrotron X-ray diffraction (carried out at the P07 beamline, PETRA-III, DESY, Germany). With varying temperature, the change of the lattice parameters of both phases are evaluated. Coefficients of lattice thermal expansion and bulk thermal expansion are compared. Evolution of microstructure with temperature will also be presented.

Cracking of Ferritic High Strength Steel during Forming

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Formability is a key parameter determining the successful implementation of advanced high strength steel grades in automotive application. High strength steels typically exhibit less formability which makes forming operations difficult. Some nanoprecipitation strengthened fine grained ferritic high strength steels (grades referred here as HS800 and HS1000) have been found to be very prone to cracking during forming. Chronic issue of cracking has been reported in HS800 and HS1000 grade hot rolled (HR) material during bending operation in the form of C shaped channel. In case of HS800 material, bending operation was carried out by roll forming whereas in HS1000 material, bending was performed in brake press machine. Detailed metallurgical and mechanical analysis was carried out to understand the root cause of the cracking phenomenon. Fracture surface of HS800 grade sample revealed crack initiation exactly from the centre location of the sheared edges and condition of sheared edges corresponding to the location of crack was found to be poor and damaged. Etched microstructures revealed multiple pearlitic segregation lines along the centreline. Whereas in HS1000 grade material, sample from cracked edge exhibited martensitic segregation lines along quarter and centrelines. Analyses suggested that in both cases, material inhomogeneities in the form of second phase formation (hard phase) and its discontinuous segregation along quarter and centrelines were leading to cracking of the material during bending. Controlling casting parameters to avoid segregation and increasing the bend radius during forming leaded to reduction in cracking.

Keywords: Advanced High Strength Steel, Forming, Bending, Cracking, Segregation

A Study on Process Optimization for Control of Percentage of Resolvable Pearlite in High Carbon Wire Rods

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In the present competitive global scenario, quality expectation for high carbon steel wire rods has become very stringent which exerts a lot of pressure on the steelmakers. These wire rods are drawn to high tensile wires, some of the applications being in pre-stressed concrete for railway sleepers and electric poles, sling wires of cranes and tyre cords. Critical rolling of superior quality wire rods, in high carbon steel (0.76-0.82% C) becomes even more demanding owing to its proximity to eutectoid point and tendency to form cementite network and higher percentage of resolvable pearlite, both of which impact the drawability of wire rods severely, leading to breakages while drawing. Presence of resolvable pearlite depend mostly on the cooling rate as a slower cooling rate leads to more amount of resolvable pearlite. Controlled cooling to get optimum laying head temperature and proper Stelmor parameters are the ways to obtain desired microstructure. In the present study, an internal procedure was developed for measurement of percentage of resolvable pearlite by optical microscopy following international standards. The focus was on controlling cooling rate, laying head temperature and thereby obtaining an optimum microstructure with resolvable pearlite within the specified limit.

Keywords: Resolvable pearlite, high carbon wire rods, laying head temperature, controlled cooling.

Development of Fe 550 SD from Quench and Tempered Route using Advance Statistical Analytics Tool

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Tata Steel is currently producing Fe500SD grade rebar (~130 kt/month) for retail segment, for almost a decade. Recently a few competitors had launched Fe550D grade in retail (also conforming to IS 13920:2016). Hence, to create a product differentiator in the market, there was a need to launch a better product than competitor's product. M&S envisaged a PAN India migration from Fe500SD to Fe550SD grade for entire retail segment. This initiated the process of NPD in all mills of Tata Steel.

New Bar Mill being the largest volume producer of 10, 12 and 16 mm rebars which goes to retail market (~2/3rd of total retail volume), the 1st priority was to develop Fe 550SD from this mill. Also, being the fastest mill and originally designed for producing Fe 415 grade, challenges to produce higher strength & higher ductility rebar i.e. Yield strength ≥ 550 along with Elongation ≥14.5% and UTS/YS ratio ≥1.15; was more in NBM.

To achieve the combination of high strength and high ductility, optimum rim fraction and core strengthening is required. YS is majorly a function of rim thickness/fraction (i.e. extent of quenching) while UTS majorly depends on core strength. Also to achieve UTS/YS ratio ≥1.15, C is kept to be 0.23 % (as carbon is restricted to 0.25 max in IS 1786). Optimum Mn addition to increase the hardenability and pearlite fraction and addition of Si to increase the ferrite strength was explored, thus increasing the core strength. Cost impact of these elements is lower than other strengthening elements (CE max- 0.61).

The results showed desired properties (YS≥570 MPa, UTS/YS≥1.15, %El≥14.5) can be achieved consistently through QST route. Advance statistical analysis like response surface method used to identify correct process parameters. With the suitable range of billet chemistry and correct water quenching parameters a new product is developed and ready for its commercial production.

After successful trials in lower sizes 8-16 mm, it was proposed to launch this product in retail with full basket of retail (8-32 mm). Hence trials were taken in other mills of Tata Steel and trials were successful. The product is developed and can be supplied in future as per the orders by marketing and sales.

Keywords: Yield strength, New bar Mill, response surface method, water quenching

Surface Crack Analysis in Hot Rolled Hypereutectoid Chromium Steel

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Surface cracks in hot rolled products are generated from certain defects such as pinholes, blow holes and deep oscillation marks from continuous cast billets or blooms and during hot rolling process. In this work, occurrence of surface crack in hot rolled hypereutectoid chromium steel is investigated with respect to casting and rolling conditions. The cracks observed in the steel grade are continuous over the surface with multiple branches of 900 µm deep across the longitudinal direction and micro cracks of 50 µm with random distribution in the transverse direction. Root causes for surface crack are analyzed based on the defect origin in the billet, internal oxidation, rolled in scale, decarburization and other metallographic features. The methods of preventing the defect such as surface grinding of as-cast billet up to 2 mm depth, optimizing billet reheating parameters and controlled cooling at the rate of <0.4 °C/sec after hot rolling are established. This resulted in elimination of surface crack in hot rolled product.

Keywords: Hypereutectoid, surface crack, hot rolled.

Avoiding the Tripping of Waste Gas Fan at Sinter Plant

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Sintering is a thermal agglomeration process where mixture of iron ore fines, ironmaking by-products, fluxes and solid fuel (coke fines, anthracite coal) are used as raw material. The purpose of the sintering process is to manufacture an iron bearing product with suitable characteristics (thermal, mechanical, physical and chemical) and it is to be charged into the blast furnace without delay. But some production delay happened due to failure in critical equipment. One of the such equipment is Waste Gas Fan (WGF). The purpose of WGF in Sinter Plant is used to transfer the heat in the sinter bed uniformly by sucking the flue gas. Heat transfer is essential for sintering. Hence stoppage/ trip of WGF leads to shutdown which will be resulted in major production loss. Among the several equipment delay WGF trip is the major contributor in the past 6 months and it contributes around 330 min delay which resulted in sinter production loss of around 825 MT. By continuous research, the root cause of this problem was identified, and it lies

in the manual control of WGF damper. The counter measure was taken with the help of Poka Yoke by auto closing program of WGF damper when current reaches the given set point. The results were validated and provides the benefit of reducing the delay time to zero from 330 min, eliminated the production loss of 825 MT and it saved the cost of 1.75 lakhs.

Keywords: Waste Gas Fan, Poka-Yoke, Production loss.

Optimization of Processing Parameters for 50C1000 Grade CRNO Si Steel with Superior Magnetic Properties

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The modified chemical composition and controlled processing parameters were established to improve the magnetic performance of 50C1000 grade Si steel. ~0.6% Si with ~0.25% Al added CRNO steel subjected to different annealing temperatures (820-870 °C) and line speed (90 – 115 mpm). Optical microstructure and XRD bulk texture measurements were employed on trial samples. Core loss decreases with increasing annealing temperature up to 855 °C after that increases due to increases in grain size inhomogeneity. On the other hand, permeability continuously decreased with increasing temperature owing to the strengthening of magnetically unfavourable gamma fibre (ND//<111>). However, the line speed, showing a nonlinear relation with core loss and permeability. The low processing speed (90–100 mpm) is strengthening unwanted gamma fibre whereas, higher speed (>110mpm) increases grain size inhomogeneities, results poor magnetic performance. 0.6% Si with 0.25% Al Steel annealed at 855-860°C with 110 mpm speed, overall magnetic properties improved by 20% (Core loss 4.96 W/Kg and magnetic permeability ~2000-2200) then the present level (Core loss 6.40 W/Kg and permeability ~1700-1750).

Keywords: CRNO Si steel, Annealing, Microstructure and Texture

Effect of Cooling Rate on Grain Coarsening in Boron Grade Wire Rod Products

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In wire rod rolling, Stelmore conveyor is used for post cooling process, in which there is edge region and center region during coil formation. Grain coarsening study were carried out along the full ring. It was evidenced that GC is more predominant in the edge region than the centre region and the actual temperature difference also was found to be more than 100 °C between these regions. In the center region, there was more ring to ring spacing which allows more heat transfer than the edge region having overlapped which delays the heat transfer. Different cooling rates by varying conveyor speed 0.2, 0.3, 0.5 m/s were selected to study the coarsening effect along the ring formation.

Keywords: Grain Coarsening, Conveyor Speed, Stelmore conveyor.

Reducing Surface Hardness Variation of Large Diameter Steel Rolls

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Quality problems encountered with High Chrome (HiCr) large diameter (>900 mm) iron rolls were investigated at Roughing Mill of Hot strip mill of Tata Steel Jamshedpur and at the premises of the roll manufacturer. It was identified that quality issues were more from one roll supplier when same operating conditions are followed for all other suppliers. Some major problems in HiCr iron rolls from a supplier were shell hardness variation, lower campaign lengths due to banding (surface degradation), roll peeling and high roll wear. Therefore, there was a need for improvement of microstructural homogeneity, fracture toughness, thermal fatigue resistance of the shell. Seeing the condition, the investigation was extended to the local roll manufacturing plant. Several analyses were done on existing hardness profiles and furnace temperature data. Some critical measurements like portable spectrometry were done to check

the variation of chemistry (Mainly C and Cr) along perimeter and barrel length of the roll. In-situ microstructure of heat-treated finished roll were done to correlate with corresponding hardness variations. Furnace control was found important to ensure desired microstructural properties and stress distribution to enable a roll hardness within acceptable specified range. Roll manufacturing was focused on the heat treatment processes, without modifications of its chemical compositions. Rough turning was introduced before heat treatment to clean the roll surface. Introduction of homogenization cycle for all cast was done in its heat treatment cycle. Forced air quenching practice and multiple tempering cycle were applied to improve the roll peeling sensitivity and to ensure a well-tempered martensitic matrix with a low level of residual austenite. As a result, hardness variations along the barrel length and circumference were reduced significantly. Inhomogeneities (e.g. soft areas) before reaching scrap diameter were also decreased.

Effect of Hot Deformation and Crystallographic Texture on Impact Toughness and Fracture Mechanism of Thermo-mechanically Rolled API-X70 Steel

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Anisotropy in Charpy impact toughness properties of API X70 steel was found to be a strong function of microstructure and crystallographic texture developed due to the thermo-mechanical processing of the steel. The microstructure of the steel was examined in detail using light optical microscope, scanning electron microscope (SEM) and the transformation textures were studied from the orientation distribution function (ODF) obtained from the electron back-scattered diffraction (EBSD) experiments. The principal components of austenite-to-ferrite transformation texture, namely the α-fiber (<110>‖ RD), the γ-fiber (<111>‖ ND) and ε-fiber (<110>‖ TD) are found to play a dominant role in the observed anisotropic behaviour and mode of fracture during impact tests. The major components like, {112}<110>, {113}<110>, {332}<113>, {111}<112>and {111}<110>, their relative intensity distribution, are found to play a crucial role towards observed impact toughness value and mode of ductile and/or cleavage fracture. The combinatorial strengths of the components of the γ-fiber, namely, {111}<112>and

{111}<110> over α-fiber , namely {112}<110> and {113}<110>, plays a significant role in increasing both the impact toughness value and favours ductile fracture. It has been observed that the anisotropy in impact toughness greatly reduced by stronger presence of ferrite grains with {332}<113>and {554}<225> orientation over {112}<110>and {113}<110> of the α-fiber. It has also been observed that, the type and extent of delamination and cleavage/quasi-cleavage fracture was mostly controlled by clustering of {100} grains in the primary and secondary cleavage over 2nd phase banding.

Keywords: Charpy Impact Toughness, Crystallographic Texture, Quasi-cleavage fracture, ferrite, cleavage-morphology clustering.

Effect of Microstructural Parameters on the Charpy Impact Toughness of AISI 1018 & AISI 4340 Steel

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The anisotropy in Charpy impact energy (CIE) was studied in two different grades of steels i.e AISI 1018 & 4340. Both AISI 1018 & 4340 steels were subjected to hot rolling having different carbon contents: 0.148 wt. % C and 0.464 wt. % C respectively. Standard Charpy impact specimens were prepared from the both the grade of steel rolled plates along various orientations such as LS, TS, LT & TL and tested at the room temperature. Microstructure, inclusions and crystallographic texture have been characterized on the plane parallel to the fracture plane of each sample. For both the steels, the LS orientation had depicted the highest average CIE while TL orientation depicted the least average CIE value. The standard deviation in CIE value was observed to be least in TS orientation while LS orientation depicted the highest. Extensive microstructural investigation using electron microscopy has revealed that CIE is strongly influenced by microstructural features such as grain size of pearlite and ferrite, their size distribution, interlamellar spacing of pearlite, volume fraction of ferrite and effect of inclusions.

Investigation of Failure of High Carbon Wires during Drawing

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High-carbon (HC) steel wires used for pre-stressed concrete, bridge cables, and tire reinforcement materials require an extremely fine diameter and high strength. Continuous cast billets are rolled to produce wire rods and subsequently drawn to fine wires for different applications. Breakage of HC wires during drawing, is such an issue which can cause rejection of tonnages. There are several probable causes of wire failure like improper lubrication, non-uniform drawing, manufacturing issue manifested with martensite or cementite segregation etc. This study aims to investigate the root cause of failure of HC wires during drawing. Several broken wire samples and their corresponding wire-rod and billet samples were collected for investigation. Detailed metallurgical investigation consisting of macrostructural and microstructural examination was carried out. Macrostructural analysis revealed segregation in the billets. Microstructural analysis of corresponding wire-rods showed presence of cementite network at the grain boundaries and/or martensite in pearlite matrix at the central line of the wire rods. These hard phases are primarily responsible for breakage of corresponding wires during downstream deformation or drawing processing. Poor control of centreline segregation during casting of HC steel is detrimental for drawability and subsequent fatigue or torsion performance. Maintaining an optimum superheat for minimisation of segregation in the casting of high carbon billets was recommended.

Keywords: Billet casting, centreline segregation, super heat, cementite network, martensite

Optimization of Continuous Annealing Parameters to Improve the Productivity as well as Spring back during Cold Roll Forming of Utility Ferritic Stainless Steel

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Utility stainless steels are a class of ferritic stainless steel which offer high strength, good weldability and high corrosion and abrasion resistance. These grades have attracted widespread global interest since their inception as these are cost effective alternatives to the conventionally used coated/galvanized carbon steels in applications particularly requiring wet abrasive corrosion resistance. One such utility grade is X2CrNi12 (EN 1.4003), a low carbon ferritic stainless steel widely used in the fabrication of freight wagons, bus body frames, rail and metro coaches.

The work presented here investigates the major cause of springback issue encountered in X2CrNi12 grade steel of 2mm thickness used during cold roll forming of carlines for Railway Coaches. The cold rolled coils are subjected to continuous annealing at a temperature close to the Ac_1 followed by water quenching and pickling. It was observed that mechanical properties post annealing at subcritical temperature showed inconsistency in strength throughout the coil. Improvement of properties was a challenge due to the apprehension of austenite formation at temperatures above Ac_1 and an increase in time could lead to lower productivity at cold rolled annealing and pickling line (CAPL).

Number of industrial trials were carried out at CAPL to identify the optimum process parameters to obtain consistency in mechanical properties with a lower yield strength so as to minimize the spring back during cold roll forming while maintaining the productivity. With the suitable modifications in annealing profile at CAPL, the mechanical properties, particularly yield strength obtained reduced to about 10-15% along with an increase in the average ferrite grain size.

This approach led to a decrease in the rejection of the material caused due to springback from 20% to <1% and in turn increased productivity at the CAPL. Thus, careful manipulation of annealing parameters is essential to obtain the desired properties.

Life improvement Journey of Granshot Ejector Pipe at Tata Steel Kalinganagar

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The GRANSHOT process converts liquid metal into granules by rapid solidification in water. Metal granules are homogenous in composition, easy to handle, store and transport. In this process, hot metal is discharged from torpedo ladles into a runner followed by a tundish and the stream of hot metal falls from tundish on a refractory striking disk, called spray head, hot metal pea/ balls thus generated fall into the water bath to form solid metal pea and it transport through ejector pipe with high water and air pressure. It is a continuous iron granules solidification process of molten metal. Iron granules transfer through ejector pipe with air & water pressure to the dewatering unit.

The granule size is varying from 5-45 mm and weight of the granules is 10-250 gm. During transportation of granules ejector pipe ceramic lining got dislodge frequently due to abnormally high water & air pressure lead to huge impact force over the ceramic lining. As the solid metal pea strikes transport through ejector pipe, the quality of ceramic lining and design plays a vital role for safe operation of gran-shot. The ejector pipe experiences extreme high impact of solid metal pea, severe abrasion. Due to any failure or breakage of the ejector pipe, would cause severe operational hazards. Considering the severity of its application, A fused alumina based high alumina ceramic composition had been developed with superior properties. The development comprises of value engineering, characterization of present and improve material, high cold abrasion resistance, high compressive strength to take the impact of solid metal pea, low water absorption (%).

Thermo-mechanical Simulation and Characterization of Railway Wheel Production

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Consistent achievement of required mechanical properties in railway wheels during production depends on the level of understanding of the influence of each process parameter involved in the complex wheel manufacturing process. An effort was taken to simulate the complete production process of R-19/1993 specification railway wheel including reheating, forging, rolling, rim spraying and tempering using the Gleeble® 3500C thermo-mechanical simulator on samples of R-19/1993 ingots obtained from Durgapur Steel Plant. Dilation studies were also carried out separately on the simulator to understand the phase transformation behaviour of the steel at different cooling rates and soaking temperatures. Following the simulation and dilation studies, the microstructures and hardness of the wheel steel were examined. The experimental results were used to understand the effect of the individual process parameters like the forging, rolling, rim spraying and tempering temperatures on the final hardness and microstructure of the railway wheel rim. It was observed that while the change in rolling and

tempering temperatures did not affect the final microstructure or hardness significantly, the forging and rim spraying temperatures had a marked effect on them in the lab scale study.

Development of Non-Leaded Free Cutting Steel

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Lead is used in steel to impart property of high machinability and hence the steels are also called Free Cutting Steels. However, lead fumes are harmful and toxic and the lead fumes which get generated during the manufacturing of leaded Steel can cause significant damage to human health and life when inhaled.

In order to minimize this hazard and threat to human being while manufacturing the steel, the non-leaded free cutting steel has been developed jointly by Tata Steel Long Products Limited, R&D of Tata Steel Limited and Technology Group of Tata Steel Limited.

The basic premise is to eliminate lead from the steel and replace it by equivalent proportion of Mn and Cr. The free cutting property which is a result of the MnS globules accompanied by lead would also be replaced by MnS Globules accompanied by Cr.

One heat has been successfully cast in the section 150 x 150 mm^2. The Macro etch samples were studied for the segregation as well as internal soundness and cast structure properties. The results have been satisfactory and further trials in rolling are in progress in both the wire rods as well as bars.

The challenges in designing, steel making, refining, and casting of the steel have been successfully overcome.

The paper discusses the various steps involved in the manufacturing right from the design stage to the casting stage and the various metallurgical parameters that have considered in the process.

Also, the cross-functional collaborations between R&D, operation and the technical team and functions in developing the chemistry and the technical parameters are also discussed in detail.

Effect of Molybdenum on Recrystallization Behavior of Fe30Mn5Al1C*x*Mo Lightweight Austenitic Steel

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Lightweight austenitic steels had been one of the materials of interest with the aim to mitigate the carbon dioxide emissions and improve the fuel efficiency in automotive sector. However, an understanding of the recrystallization behavior of these steels would open the door for, to explore a spectrum of structural application demanding a balanced strength-ductility. Therefore, a systematic study to understand the static recrystallization behavior of designed and processed alloy is the objective of present work. The designed alloys (Fe30Mn5Al1C-*x*Mo) prepared through induction melting route followed by homogenization, hot forging and hot rolling. The hot rolled alloys were cold rolled to ~80% reduction in thickness and isochronally (1 hr) annealed between 600-1200 °C. The microstructural evolution with quantitative measure of recrystallization perceived through EBSD based grain orientation spread (GOS) maps. Vickers hardness obtained to support the recrystallization fraction (f_{rcx}) at each stage and the corresponding strength. Furthermore, thermal analysis technique DSC is utilized to identify the change in activation energy with increase in molybdenum concentration. The results indicated that an increase in molybdenum caused a shift in the recrystallization temperature (T_{rcx}) from 700 °C in 0-Mo to ~800 °C in higher molybdenum alloys, attributed to retarding effect on the recrystallization kinetics. The results suggest that understanding of the recrystallization behaviour of present alloys provides means to further investigation on control of grain size and its related effect with varying molybdenum.

Keywords: Lightweight austenitic steels, EBSD, DSC, Recrystallization behaviour.

Texture and Mechanical Properties Improvement of AISI 409L Cold Rolled Sheets by Modifying the Processing Routes

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AISI 409L is a Ti-stabilized ferritic stainless steel grade containing about 11 % Cr. 409L is primarily suited for the manufacture of automobile exhaust system because of its good oxidation resistance up to 800 ˚C, good weldability and formability. Changes in the emission control norms demand material with increased drawability and ductility to meet the requirements. The present study aims to develop 409L to achieve high formability by using EMS to ensure 50% minimum equiaxed in the cast structure, low finishing hot rolling temperature and minimum 70% cold reduction followed by increased annealing temperature to develop uniform equiaxed grains and increased γ- fiber fractions in final microstructure. The material processed through modified routes is having a minimum R- bar value of 1.45 and elongation of 34% fulfilling the requirement of the increased draw height and complex drawn components.

Keywords: Ti-stabilized ferritic stainless steel, drawability, gamma fiber, R bar.

High Temperature Deformation Behavior of a Low Carbon Micro Alloyed Steel and its Deformation Optimization using Processing Maps

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Thermomechanical processing of microalloyed steels requires a complete understanding on its high temperature flow behavior, which is governed by several simultaneous microstructure phenomena such as work hardening, static and dynamic softening processes and interphase solute precipitation. Therefore, the deformation temperature, strain rate, strain and inter pass times during high temperature deformation must be carefully controlled to achieve the required microstructure and mechanical properties. In the present study, high temperature deformation behavior of low carbon, niobium microalloyed steel was investigated using plain strain compression test on Gleeble thermomechanical simulator. Plain strain compression tests were conducted on samples in the temperature range 850 to 1050 °C and strain rate range in the range 0.1 to 50 sec^{-1}. The stress-strain curves exhibited flow softening by dynamic recrystallization especially at high temperature and low strain rates. A relationship among the flow stress, deformation temperature and strain rate was obtained using hyperbolic sin Arrhenius type equation and the predicted deformation parameters were validated against the experimental results. A deformation processing map was developed using dynamic material model in the experimental range and the optimum working domain identified by the processing map was validated by deformation characteristics and microstructural studies. Iso-activation energy map revealed the presence of an activation energy plateau in the temperature range of 1000 to 1050 ºC and a strain rate range of 1 to 10 sec^{-1} and is in accordance with the safe processing domain identified by the processing map. The developed processing map may be used to optimize the hot working process parameters to obtain required microstructure and mechanical properties.

Keywords: Microalloyed steel, Plain strain compression test, dynamic recrystallization, Processing map

Insights & Observation for Optimum Work Roll Cooling in Flat Hot Mills: A Case Study on Shape Defect Elimination

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Tata Steel Bhushan Steel Ltd.(TSBSL)'s hot mill at Angul, Odisha, India was facing shape issues in hot rolled (HR) coils. This was resulting in a defect called as 'Ridge' which was appearing in subsequent cold rolling operations at various cold mills (CRM) and external customers. A collaborative project was undertaken to resolve this issue.
One of the reasons identified was the strange drop in thermal crown after rolling of 20-25 coils in the finishing mill (FM) schedule. On the shop floor, it was observed that work roll temperatures in the FM after rolling were very high and non-uniform across the work roll barrel. Jammed work roll cooling nozzles, insufficient roll bite lubrication and inadequate roll cooling water quality were found to be the main reasons.

Regular checking was initiated to check roll cooling nozzles health and quick replacement done if found jammed was implemented. Improvements on roll lubrication especially flow rates were done. Usage of anti-peeling headers and inter stand descaling was enhanced. A subsequent project was also taken up for improving the quality of roll cooling water.
Encouraging results were obtained from the project with a reduction in rejection due to ridge at CRM's by almost 95% of the pre-project start levels. Poor profile occurrence of HR coils at HSM was also reduced from a high of 32% in May'19 to <1% since Apr'20.

Tinplate Surface Brightness Improvement by Substrate Steel Aluminium Nitride Refinement

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Tinplate is light gauge, cold-reduced low-carbon steel sheet or strip, coated on both faces with commercially pure tin. It thus combines in one material the strength and formability of steel and the corrosion resistance, solderability and good appearance of tin. Within this broad description, there exists today an extremely wide range of products, tailor-made to meet end-use requirements. Production of the steel base and its subsequent coating with tin are independent of each other, so that any set of properties in the steel, can in theory be combined with any tin coating. The composition of the steel used for tinplate is closely controlled and according to the grade chosen and its manufacturing process, various types with different formabilities ("tempers") can be produced. The surface brightness/gloss is a combination effect of substrate steel and tin coating thickness, nowadays tinplate industry is moving to low tin coating, hence for better surface aesthetic (brightness) substrate steel contributes to surface brightness by refinement of crystal structure.
The brightness of steel substrate can majorly be controlled by orientation of crystal lattice in a particular plane. To achieve the desired lattice plane, precipitation of aluminum during re-crystallization (batch annealing) helps in grain refinement.
A controlled batch annealing process helps in desired Al-N precipitation resulting in grain orientation and thus the brightness of steel substrate.

Evaluation of Corrosion Resistance in Bare Steel, Coated/Painted Steel to identify Cost Efficient Approach

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Corrosion plays a crucial role in determining the long term durability of steel structures. The life of metallic components depends on its application, mechanical behaviour and corrosion susceptibility. The life expectancy of components depends on the materials specification, design of the component, and exposure to the environment such as relative humidity, temperature, salinity, weather condition, corrosive gases (CO_2, SO_2, H_2S etc.), etc. The cost of corrosion protection involves suitable material selection, design of component, coating/painting application, cathodic/anodic protection, welding techniques, and maintenance practices.
The present study aims at to understand the corrosion behaviour and corrosion life assessment of normal structural steel, weather resistance steel, galvanized steel and painted steel over same structural steel. Salt spray fog test and potentio-dynamic polarisation tests have been utilised to measure the corrosion potential/rate in different steel substrates. The corrosion behaviour and cost implications for the above steels are compared with stainless steel and aluminium. The paper also signifies suitable approaches for corrosion protection for growing infrastructure demand in India.

Optimization of Batch Annealing Furnace Bay

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The annealing process is a foremost and critical operation in the production of cold rolled steel coil, which significantly influences final product quality in terms of mechanical properties as well as surface finish. In any BAF, the bases in a bay share its common resources such as heating hoods, cooling hoods and EOT cranes at different phases of the annealing cycle. The efficiency of each of these entities may vary depending on various factors like burner conditions, age, crane cycle

time and the thermal load of the charge i.e., weight & dimensions of the coils. More often, one encounters the situations wherein the occurrence of simultaneous demand for the common resources may lead by multiple bases, which cannot be met and as a result, delay might occur in handling some of BAF bases.
To overcome such problem a hybrid modelling approach was opted to predict important cycle events such as soaking end time, heating hood (HH) cooling, cooling hood (CH) cooling, by-pass cooling etc. The said hybrid modelling method incorporated with first principle as well as random forest mathematical technique, wherein the prediction of annealing cycle events has enabled optimal allocation of charges, forecasting full annealing cycle (current and next cycle), demand for different equipment & resources. This in turn minimizes demand clash during annealing cycle or delays minimization due to unavailability of equipment. At the beginning of cycle, heating and cooling time were predicted using random forest for regression and as the actual process being in progress, the predicted heating and cooling time were fine-tuned by using first principle-based heat transfer model. A good correlation has been obtained between predicted and actual data where, the mean absolute error of 0.6142 deg., 0.9202 deg. and 0.4728 deg. in by-pass cooling, HH cooling and CH cooling time prediction was recorded respectively.

Keywords: Batch annealing Furnace, cycle time prediction, Shop Optimization, Random forest for regression, delay minimizations.

Computer Vision based Application for Detecting and Classifying of Center Line Segregation and Internal Crack for Steel Slabs from Sulphur Print Image

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Computer vision (CV) is an interdisciplinary scientific field that deals with, how computers can gain high-level understanding from digital images or videos. Modernization of technology in steel industry demands advanced applications like AI for digitizing and smoothing its operations. Cast slabs are hot rolled to produce semi-finished products (strip or plate). During solidification of the steel results in the formation of centerline segregation (CLS) as well as different types of internal cracks (ICC) which are function of the casting process as well as the chemistry of the steel casted. In this context, it has been discussed that how computer vision based digital image analysis technology can ease for detecting and classifying defects and its severity. Various types of internal defects like centre line segregation, transverse and longitudinal internal cracks, triple point crack, black spots etc are formed during slab casting operation in conventional slab caster. Those defects are identified while slab transverse inner surface is placed on a bromide paper after etching by sulphuric acid and therefore, internal slab surface defects are printed on that paper. Typically, classification of those defects is carried out manually with comparing to the standard images (Mannesmann and VDEh standard) by visual observation which resulted an obvious discrimination of defects severity analysis. Even poor repeatability of the test results also can be observed. To minimize the manual assessment, a quantitative model has been developed which can assess the defect classes quantitatively from sulphur printed image. Initially, standard images are quantified by using advanced digital image analysis technology and those standard structured data are used as reference for the assessment of defects and its severity for all input images. The developed model shows above 90% accuracy which indicates that the model can be implemented in operation for quality management of cast slabs.

Root Cause Analysis of 'Black Edge' Defect in Hot Dip Galvanized Steel

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The galvanized steel sheets are known for their excellent corrosion resistance, hence are extensively used in many applications. Producing defect-free galvanized steel sheets for steel industries is challenging. 'Blackened' edge (referred to as 'Black Edge' from here onwards) is one of the chronic surface defects which appears throughout the cold rolled coil edges. This defect leads to quality losses as it gets revealed after the completion of the galvanizing process. The defect manifests as the absence of a coating layer on the edges which can lead to accelerated corrosion from the edge location. It also decreases the aesthetic value of the galvanized product. Due to this, it renders the steel sheets inappropriate for the intended application, amounting to their rejection. In this work, the 'Black Edge' defect associated with hot-dip galvanized steel is investigated for its root cause. The analysis includes a comparison between multiple good and defective galvanized samples and their respective bare full hard cold rolled (FHCR) samples. Morphology and chemical composition of defective edges were analyzed under Scanning Electron Microscope equipped with Energy Dispersive X-ray Spectroscopy. At the defect location, the absence of coating was evident along with the presence of iron oxide peaks. It was found that edge morphologies of FHCR samples corresponding to defect samples were highly uneven and were associated with deeper cracks compared to good samples. Crack surfaces were non-linear and had a certain depth. Within cracks, carbonaceous material entrapment was observed. The investigation suggested that the entrapment of carbonaceous material during the processing of material for galvanizing decreased the wettability of zinc during the galvanizing process. This caused the 'Black Edge' defect.

Keywords: Steel, Cold rolling, Galvanizing, Edge defect.

Comparison of Tinplate Grade Produced through Batch Annealing and Continuous Annealing

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Tinplate is typically a thin sheet of steel that is coated with thin layer of tin metal and its alloys. The substrate is either cold rolled continuous annealed (CRCA) or cold rolled batch annealed (CRBA) over which tin or tin alloy plating is done. The process of manufacturing of tin plate involves hot rolling of a coil which is further cold rolled, after cold rolling annealing is done. Subsequently skin pass rolling and finally tin plating is incorporated. Major property requirement of tin plate includes excellent formability and corrosion resistance, superior weldability, optimized strength and ductility. Most of the tin plate applications like food cans, non food cans, etc. requires excellent formability. There are two different annealing routes of manufacturing of tin plate grades that are via Batch annealing (BA) or Continuous annealing (CA). These two routes have their pros and cons. Continuous annealing is best for good productivity due to shorter annealing time, whereas batch annealing is better for achieving higher formability. Formability is compromised in case of CA due to shorter annealing time, whereas productivity is compromised in case of BA. Low temper grades such as T1, T2 and T3 are manufactured via BA route. High hardness observed in the product via CA route. Shorter annealing time which reflects in finer grain size is main reason of high hardness in CA route sample.

In the present study three low carbon based tin plate grades - T53, T55 and T61 are processed with 80-90% cold reductions with CA and BA temperatures being about 700-800 °C and 550-600 °C respectively. The effect of chemistry, process routes followed and its effect on ensuing microstructure and mechanical properties of the products developed are compared. It is observed that coarser ferrite grains obtained through BA process led to better formability.

Mathematical Modelling of Heat Transfer and Phase Transformation During ROT Cooling of CSP mill

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A mathematical model is developed to predict the heat transfer and phase transformation during run-out table (ROT) cooling of hot rolled strip cooled at CSP mill of JSW Steel - Dolvi Works. The developed model incorporates the cooling characteristics of different zones of ROT (air, ultrafast, laminar and trim zone), the austenite-ferrite phase transformation kinetics as function of ROT length and the latent heat of transformation. The equilibrium cooling conditions for phase transformation are simulated using lever rule. For simulating the non-equilibrium conditions, the ferrite incubation and growth periods are treated separately using Scheil's method and the JMAK equation, respectively. The temperature profile of the strip (through thickness) calculation is carried out using the governing heat conduction equation by employing finite difference methodology. An internal heat source term has been included to take into account the latent heat generated by the phase transformation. The sensitivity analysis of model was carried out to understand the influence of strip thickness and strip velocity in controlling the final coiling temperature. The time–temperature measurements during cooling of a low carbon steel at different locations together with the microstructural studies have been performed to verify and validate the ROT model predictions. In addition, the continuous-cooling dilation tests were performed on a Bähr DIL 805 A/D dilatometer to simulate the phase transformation kinetics at temperatures and cooling rates similar to CSP ROT conditions. The comparison between model predictions and plant experimental measurements indicates good reliability of proposed model for estimation of CT and thermal profile across the length of hot rolled strip. The model can be employed as a guideline to design new cooling programs for achieving the desired microstructure and mechanical properties.

Reduction in Trimming Loss at Wire Rod Mill (Tatasteel)

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In wire rod mill during rolling thinner section wire rods the front and tail of the coil is left un-cooled to avoid cobble in as the column strength of the bar is not adequate to take care of resistance in water boxes. Time of opening of the water boxes and their synchronization are critical for determination of length of rod left uncooled. In the current project is to optimize water box opening time to reduce the no of uncooled ring falling on the STELMOR and thereby reducing trimming. Innovative method was used to track the opening time of the water boxes in the form of trends by creating using virtual signals in Iba data acquisition system using expressions.
The resistance in water box depends on the timing of opening of water boxes. When the front of the bar reaches laying head additional pulling action works on the bar to overcome the resistance. Timing is normally control by PLC through tracking with a lower limit and an upper limit to avoid cobbles due to operator’s mistake. There was common program for all section the magnitude of safety factor in terms of avoiding cobble was different for different sections. Measurement for these timings were taken for each by keeping the markers at the reference signal and the WB opening command signal and noting the difference in the temporal scale. Expressions were used to obtain these timings for all the bars which can now be seen in time scale. Timing trends were studied for various campaign to understand the effect of mill speed and operator's input to control the no. of uncooled rings. It gave insights for identifying actionable points to reduce number of uncooled ring while avoiding cobble.

Keywords: Wire-rods, water-box, uncooled ring.

Comparative Study for Machinability of Austenitic Stainless Steels

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The study investigates the machinability characteristics of three different types of austenitic stainless steels through a series of experiments. Understanding the machinability would assist in effective metal cutting and milling operations. Chip geometry, surface finish and tool wear are considered as the performance characteristics for machinability. The experiments were performed on 304L, 316L & 316F. Face milling operation was carried out on a CNC horizontal milling machine with cutting edges made up of tungsten carbide. The experimental design consists of conducting trials at higher cutting speed with higher depth of cut and lower cutting speed with lower depth of cut. When machining 304L and 316L at higher speed and higher depth of cut, longer helical chips segments were observed. Chips obtained when machining 316F at higher speed and higher depth of cut was friendlier to machine and generally produced small spiral segments. Helical chips were pre-dominant when machined 316L at lower speed and lower depth of cut. Chips obtained when machining 304L & 316F at lower speed and lower depth of cut generally produced lower ribbon & small spiral segments. Chip geometry shows that machinability performance for 316F is better than 304L & 316L. The machined samples are then subjected to surface roughness testing (Ra). Surface roughness of 316F is found to be lowest for both sets of parameters. The study also demonstrates tool wear after machining these austenitic stainless steels. Results showed that tool wear was highest in case of 316L & lowest in case of 316F for both cutting speeds. From the above sets of experiments, it is evident that among these austenitic stainless steels, 316F has the best machinability performance. 316F consists of higher sulphur (0.2%) as compared to other austenitic stainless steel. SEM-EDX analysis of 316F shows that it forms manganese sulphide inclusions which are soft and acts as a dry lubricant hence reducing frictional force on the interface at the time of machining.

Effect of Tempering Condition on Mechanical Properties of a 16Cr-6Ni Austenitic-Martensitic Stainless Steel at RT and 77 K

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Austenitic-martensitic transition class stainless steels have become a material of choice for many advanced engineering applications that require excellent strength toughness combination at cryogenic, ambient and elevated temperatures. It derives its strength from martensitic transformation which happens during quenching from austenitizing temperature followed by subzero treatment. The superior plasticity is due to the TRIP effect which is a result of the phase transformation. This steel has corrosion resistance superior to that of the hardenable 400 series martensitic stainless steels and better mechanical properties than the precipitation hardened grades in various environments. This steel has been reported to have excellent compatibility with LOX/LH2.
Heat treatment has been carried out in a 16Cr-6Ni steel (ICSS-0716-301) at austenizing at 990 °C followed by sub-zero treatment -70 °C. Tempering was carried out on two sets of heat-treated samples at 250°C and 400°C. The present work focuses on effect of the tempering on mechanical properties and microstructure of the material in both temper condition at ambient and cryogenic temperatures. Tensile tests and Charpy impact tests at room temperature and 77 K were carried out on both set of samples. Measurement of retained austenite, prior austenite grain size and micro structural analysis were carried out to explain the observed phenomena. Tempering conditions significantly affected their strength and impact toughness. Strength increased on the samples tempered at 250 °C at room temperature compared to 400 °C tempered samples, whereas the at cryogenic temperature strength of 400 °C tempered samples showed higher strength. The tempering temperature and thereby the retained austenite were observed to be the major factors that influence strength and impact toughness at cryogenic temperature for 16Cr-6Ni steel.

Keywords: 16Cr-6Ni steel, hardening, subzero treatment, tempering, tensile strength, impact toughness and retained austenite

Cementite Spheroidization Process in High Carbon Steel with Different Manganese, Chromium, Vanadium and Tungsten Contents

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The cementite spheroidization process is investigated in high carbon steels with different manganese, chromium, vanadium and tungsten contents. During spheroidization annealing process of high carbon steels, divorced eutectoid transformation (DET) reaction leads to spheroidized structure. In the current study, spheroidization behaviour of three steel grades were studied- plain high carbon steel with 0.45% Mn, high carbon steel with vanadium, tungsten and 0.45% Mn, the third steel contains vanadium, chromium, tungsten with 1.1% Mn. All the steel grades are rolled to final wire rod product with size 5.5 mm. First grade is Stelmor conveyor faster cooled and the other two grades are control cooled. The interlamellar spacing with different cooling conditions

was analyzed and its effect on degree of spheroidizaton was examined. The influence of various alloying elements Cr, Mn, W and V on austenization temperature, degree of spheroidization and DET reaction was analyzed.

Keywords: Spheroidization, Cementite, Stelmor.

Development of Cost Effective Bell Annealing Cycle for Low Chromium Ferritic Grades in Auto Application

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Ferritic stainless steels containing less than 14% chromium are batch annealed in order to transform the martensite formed during hot rolling. Batch annealing is done by stacking coils on fixed bases keeping the coils intact in small furnaces and hence require a longer heating and cooling time leading to an extensive annealing cycle. Hence decreasing the total bell annealing cycle time by even a few hours would lead to an increased productivity. The present study aims at optimizing the bell annealing cycle of the grade 410 for auto application by a minimum of 20 hr by lab scale trials followed by commercial application, while not compromising the properties of the material. Accordingly, simulation studies were carried out in muffle furnace with higher heating rates and lesser soaking time followed by various rates of cooling (quenching, water cooling and furnace cooling) and analyzing the change in hardness and microstructre for each simulation. It was observed that in all these experimental cases a well-developed grain structure and optimum hardness is obtained by reducing the soaking time. Faster heating and cooling rates followed by furnace cooling and an increased coil out temperature were found to give the best possible outcome. Owing to these favourable results, industrial trials were taken in bell furnace for mass production with reduced soaking time, faster heating and cooling rates along with an increased coil out temperature. Both the trials showed a significant decrease in bell cycle time, with desired properties. Multiple plant scale trials were further conducted and the average total bell annealing cycle time was reduced from 78 hr to 52 hr in the grade 410 for auto application. With the existing capacity, an increase in productivity of ~3000 tonnes/month could be achieved by this bell cycle modification.

Development of SQUARE 125 Pass Schedule at MMSM in order to meet Market Demand

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Medium Merchant & Structural Mill (MMSM) of VSP is a versatile mill in RINL with a capacity of 0.85 MTPA, which produces various medium structural and merchant products like angles, beams, channels, round and square billets in varied dimensions and caters to the different industries like automobile, general engineering, bright bar and re-rolling (TLT sector, automobile etc.) industries across the globe. 250 X 250 X 6000 mm^3 blooms are the input from Steel Melt Shop-1. It is a two high, single strand torsion-free continuous hot rolling mill consisting roughing, intermediate and finishing mill trains (RMT– 8 stands, IMT– 6 stands & FMT– 6 stands) with a combination of horizontal / vertical / universal stands.

The paper discusses about the evolution of SQUARE 125 billets and its roll pass schedule in MMSM at Visakhapatnam steel plant. There was a demand in the market for SQ125 billets, so far VSP produces square billets in various sizes viz SQ55, SQ65, SQ77 and SQ90 at MMSM. Whereas, SQ125 billets are produced in breakdown mill of LMMM for the purpose of internal consumption at Wire Rod Mill – 1 (WRM1) and bar mill of LMMM. Whatever production made at LMMM is completely consumed at WRM1 and bar mill. If the market demand of SQ125 gets fulfilled with LMMM billets, there will be a huge input dearth created for WRM1 and bar mill, which will result in decreasing production levels at both the highly demanded mills, subsequently losing the market at other places, which is not viable.

At the same time, there was a low demand for the merchant products produced at MMSM due to the ongoing global pandemic of COVID-19, which has made way for throttle down the steel production at SMS1. At this juncture MMSM has made a successful trail for developing a suitable roll pass schedule, by using the resources available internally in association with Roll Shop, in order to produce SQ125 billets. This attempt has made a way to overcome three major challenges i.e. 1) Fulfilment of market demand for SQ125 billets and capturing new markets, 2) Uninterrupted steel production at SMS1 and 3) Overcame the low market demand for MMSM products with adding new product SQ125.

Keyword: Torsion-free, Strand, Stand, two high, Roughing, Intermediate, Finishing, Hot Rolling, Bright bar, Automobile, Bloom, Structural, Round, Square, Billet, Roll Pass, Universal, RMT, IMT, FMT, Breakdown mill, WRM and Bar mill.

Customer Satisfaction through Ensuring Prime Length Rebars

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In New Bar Mill (NBM), Tata Steel, billet (of cross-section 150 x150 mm^2) is rolled into rebars of three cross sections namely 10, 12 and 16 mm. The final thermomechanically treated rebar comes to cooling bed to complete the tempering process in normal ambient temperature. After length optimization, bars fall on cooling bed at the multiple of 12 m length (Maximum: 72 m, Minimum: 24 m) and are cut into prime length of 12 m to be supplied to the customer. Neither short length rebars (rebars of length less than 12 m) nor long length rebars (rebars of length greater than 12 m) to be supplied to the customer. But it is very difficult to ensure whether the rebars which are being cut are of exact 12 m as the cutting process of rebars takes place in layers and are cut manually by the operator with shear machine, cut against visual markings of 12 m. But in a single day, more than 1000 bundles with 500 rebars in each bundle is produced. So, there is always chance of wrong length of rebars being cut by the operator.
To overcome this problem of cutting short length rebars or long length bars, various interlocks have been provided with the help of intelligent rebars tracking devices at 12 m which don't let the operator to cut the rebars layers if they are not of 12 m in length as the cut command to shear machine won't be initiated even if the operator try to cut. Also, further interlock checks have been provided at the bundle forming stations to prevent the rebars of short or long length going into the prime bundles.
This innovation has helped us to eliminate the chance of customer dis-satisfaction and complaints whose mitigation plan was earlier based on administrative control only but now active interlocks barrier has been deployed which has provided fool proof solution. This has reduced the total internal rejection of rebar bundles by more than 75%.

Keywords: Rebars, prime bundle, sensor, interlock, Tata Steel.

Resolution of Cracking in Long Member Component of 3W

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Chassis Parts of 3W has moved from IS 1079 HR2 to E-34 grade to reduce weight of vehicle. E-34 grade has higher Yield strength (333 MPa min.) than HR2 grade. Out of these chassis parts in component called as long member, which bears weight of chassis, problem of cracking was reported in E-34 supplies. This cracking was observed intermittently in few batches, and cracking percentage was found to be 3% of overall supplies. Current paper investigates possible reasons for this cracking. During investigation crack was not found to be associated with mechanical properties or any microstructural abnormality. So, forming simulation analysis was done for this component. To do this activity, CAD drawing was generated by reverse scanning. For this simulation, Hill's 48 criteria was used. These simulation studies indicated that failure is not related to global formability but w.r.t. local formability of material. Hole Expansion ratio (HER) which is measure of local formability, found to be okay as per this grade. To avoid these cracking related problems, trials were taken by buffing operation of edges of few blanks. During this trial, no cracking was observed. Further trials were taken by buffing operation of blanks, which eliminated cracking. This long member cracking was reduced to less than 0.5% of overall supplies post this change.

Improved Design of Strip Rinsing and Squeezing Systems for a Pickling Line of Cold Rolling Mill

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Pickled coils processed at cold rolling mill are required to have bright surface without acid and salt carryovers. Pickling line is therefore provided with rinsing and squeezing systems after acid tanks. Rinsing system consists of cold and hot water tanks with pumps and spray-headers for strip washing. Its effectiveness depends on impact and coverage of water-spray. Squeezing system consists of few pairs of squeezer rolls, pressed against each other, to arrest fluid carryover. Its

effectiveness depends on pressurising mechanism. One of the pickling lines was having rinsing system with three cold and two hot water tanks and its squeezing system had seven pairs of squeezer rolls. These systems were not effective in arresting acid and salts carryovers completely due to deficiencies in their design and installation layout. Top rinsing headers were fixed in tank-covers which increased spray height and reduced impact. Use of hoses with headers caused frequent leakages and lower water level in the tanks. The squeezing system had spring loaded pressurising mechanism which required frequent manual adjustments and was not effective in complete removal of fluid.

The rinsing system was redesigned to incorporate new spray headers with flat jet nozzles and fixed piping. Top spray headers were relocated from cover to body of the tank to reduce spray height and to avoid the need for dismantling it during maintenance work. With these modifications, spray impact and coverage increased and water leakages stopped. The squeezing system was modified to incorporate pneumatic pressurising mechanism in place of the spring-loaded mechanism. It included pneumatic cylinders with proper housing, air supply line, valve-stand, air-dryer, etc., which helped in achieving optimum and uniform pressure for effective squeezing. Performance evaluation of the modified systems revealed improvement in surface reflectance by 12% and reduction in surface chloride by 40% leading to brighter strip surface.

Live Current Electrodeposition of Nickel on Zinc Substrate from Modified Watt's Bath

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Electrodeposition of zinc nickel alloy coating by codeposition or multilayer deposition on steel is an important industrial process. The zinc nickel alloys have unique properties of higher corrosion resistance, wear resistance and high temperature stability. However, the plating of nickel over zinc layer has inherent problem due to preferential dissolution of zinc in the conventional acidic nickel electrolytes. Conventionally a copper strike layer is introduced over zinc followed by nickel electroplating. The present work aims at understanding the effect of both Ni^{2+} ion concentration and live currents on the feasibility and quality of Ni deposition on Zn from a modified Watt's bath. The coating thickness, coating appearance and roughness as well as electrolyte solution stability were strongly dependent on nickel iron concentration in the plating solution. The live current density has the effect on zinc dissolution from the surface. The optimized range of parameters are

finally presented to directly (without copper strike layer) deposit Ni on Zn without hampering the deposit quality.

Optimization of Laser Welding Parameters for High Carbon and High Silicon Grades

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CO_2 laser beam welding is practiced for coil to coil welding during cold rolling for increased productivity. Laser welding is a highly efficient low heat input welding offering narrow and deep welds at room temperature but experiences higher weld failure instances in high carbon and high silicon due to metallurgical reasons. In the present work, a high carbon (0.28 % C) and a high silicon grade (2.7 % Si) was selected and welded under different welding parameters such as weld speed, laser power, preheat and post-heat treatments to study their effect on weld quality and change in metallurgical characteristics. Welding was performed online on a 15kW CO_2 laser welder installed at the pickling line of JSW Steel Ltd. with a 2.5% Si limit welding capacity. Weld quality was characterized through Erichsen cupping tests. The microstructure was examined by optical and scanning electron microscopy, and mechanical property characterization was carried out by measuring micro-hardness and tensile strength across the weld. The mechanical inhomogeneity at the weld interface was the key factor responsible for weld failure and was significantly affected by laser power and speed. In high carbon grades, the combination of low laser power and weld speed resulted in inhomogeneous welds with improper fusion, but high laser power and weld speed produced good quality welds. High silicon grade welding required low laser power and low welding speed for best results. Welding high silicon grades at higher values resulted in hard bainitic–martensitic phases at the weld interface resulting in a higher hardness gradient between the HAZ and parent metal. This optimization study for these critical grades resulted in a decrease in salvaging tonnage due to weld failures.

Weldability Study of Transformation Induced Plasticity Automotive Steels

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Advanced high-strength steels (AHSS) are growing in demand in automotive industry for weight reduction, leading to improved fuel efficiency, reduced CO_2 emission and greater safety. Weldability is an important aspect of automotive fabrication and resistance spot welding of Transformation induced plasticity (TRIP) steels is an important joining processes. Resistance spot welding of TRIP steels affect the weld integrity. In the present study, weldability of TRIP 690 and TRIP 980 was studied as a function of welding parameters that includes welding current, weld force and welding time on a welding simulator. The microstructure of the steel and its mechanical properties was examined. The characterization included measurements of nugget diameter, weld hardness, weld strength, tensile shear strength, weld failure mode, and sticking behaviour. The microstructure and mechanical properties of TRIP 690 was compared with TRIP 980 AHSS spot welds and correlated to the weld operating parameters. The result shows that resistance spot welding has higher strength with weld current, up to expulsion in both the grades. There is a tendency of weld softening in the heat affected zones of a TRIP steel. The weld strength of TRIP 690 is better than TRIP 980.

Keywords: Resistance spot welding, Advanced high strength steel, Transformation induced plasticity steel, Tensile shear strength and Microstructure.

Effect of Post-weld Heat Treatment on the Interface Microstructure of Explosive Welded Titanium Alloy Tube to Stainless Steel Rod

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Titanium alloy/stainless steel transition joint components are used as end adaptors/transition tubes of gas bottles in cryogenic stages of launch vehicles and satellites. Challenges associated with titanium and stainless-steel welding are their large difference in physical properties like melting point, density and thermal conductivity. These characteristic of the above alloys makes

conventional fusion welding difficult. Solid state welding processes that limit the extent of inter-mixing are generally employed for joining titanium to stainless steel and many such dissimilar metal combination. Few solid-state joining techniques includes diffusion welding, friction welding and explosive welding.

Explosive welding is a solid-state metal-joining process that uses explosive force to create an electron-sharing metallurgical bond between two metal components. Detonation of explosives produces high velocity oblique collision, which leads to severe, but localized plastic flow at the interacting surfaces. Explosion welding is an effective joining method for virtually any combination of metals in any size.

Explosive welding of Ti3Al2.5V half alloy tube (25 mm O.D. X 1 mm wall thick) to SS304L rod (20 mm dia. X 250 mm length) was carried out with a new bonding setup. Clad rod was subjected to interface characterization in both directions. The clad rod was subjected to heat treatment process at temperature ranges of 650–950 °C. Investigations were carried out by using optical microscopy (OM), scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). The results show that post-heating of the clad rod in these temperatures results in formation of intermetallic phases at the joint interface.

Development of MIG Quality Wire Rods at IISCO Steel Plant

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Metal inert gas (MIG) welding is a welding technique in which the weld pool is prevented from the absorption of oxygen from the atmosphere by shielding the weld pool with an inert gas shield. In contrast to manual metal arc welding (MMAW), which utilizes consumable electrode in the form of short small diameter rod, MIG welding utilizes a consumable steel electrode continuously supplied from a wire spool. This steel is characterized by low carbon levels (<0.08%) and extraordinarily high silicon levels (>0.8%). Low carbon imparts high ductility to enable the wire rods of this grade to be drawn down to 0.6 to 1.6 mm diameter wires from 5.5 mm wire rods. On the other hand, to increase the soundness of the weld in terms of porosity, silicon is the most commonly employed deoxidizing element in wires used for MIG welding. Generally, MIG wires contain 0.40% to 1.00% Si, depending on their intended use. In this percentage range, silicon

exhibits very good deoxidizing ability. Increasing amounts of Si will increase the strength of the weld with only a small decrease in the ductility and toughness. However, above 1-1.2% Si, the weld metal may become crack sensitive.
To cater to the demand of the MIG electrode steel grade, ISP undertook the development of this grade. The challenge arose from the fact that ferroalloys (SiMn, FeMn and FeSi) added to achieve high levels of silicon and manganese made it difficult to keep carbon levels low as these ferroalloys inherently contain some carbon. Additionally, high silicon also called for the modification of casting cooling parameters compared to normal steel grades. Moreover, as this grade demands high reduction in area (≈ 80%), the rolling parameters at the wire rod mill were also needed to be modified. The present paper delves into the aforementioned problems and their solutions that led to the successful development of this grade.

Development of Boron Steel for Fastener Applications at Visakhapatnam Steel Plant, RINL

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High strength bars of the cold heading steel grades SAE 10B21, 15B25, 19MnB4 and 10B33 with good hardenability and core hardness have been developed for fastener applications. These grades were produced through BF-BOF-LRF-RH-CCM-WRM route. RH degasser is used to remove the dissolved gases present in molten steel necessary for the production of high quality boron steel. The bars have been rolled at TMR temperature and rates employing natural cooling and retarded STELMOR set up. Rolling was carried out at lower temperature to produce fine grain sizes resulting in better ductility in product.
These bars were produced in sizes of φ8 mm, φ12 mm and φ16 mm with 80% upset by alloying with boron and chromium. In case of 19MnB4 and 10B33 the upset requirement is 70%, because of its high carbon content above 0.30%. These two grades were successfully rolled in 20 mm and 25mm. The improved core hardness of this grade steel has been attributed to the presence of boron, low phosphorus, low nitrogen and small amount of chromium. Effect of boron was increased by controlling nitrogen in steel making, and retarded cooling in rolling of final product. Microstructural characterization was done to understand the phase distribution. Details of industrial trials are presented in this paper.

Keywords: Hardenability, Core hardness, upsetting, SAE 10B21, SAE 15B25, 19MnB4 and 10B33.

Microstructure and Mechanical Behaviour of Resistance Spot Welded AISI-1008 Steel and Al-1100 with the Introduction of Graphene Nanoplatelets as an Interlayer Coating

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Resistance spot welding (RSW) of dissimilar metals (AISI-1008 steel and Al-1100 alloy) with the introduction of graphene nanoplatelets (GNPs) as an interlayer is reported in this study. The drop-coating technique was used to put these GNPs into the steel and the aluminium plates, and they were joined by the RSW method. The ultimate tensile loads of these dissimilar lap joints processed at different welding current/time conditions were obtained by lap-shear tests, and a comparative study was carried out between the GNP-coated and bare specimens. While the weld strength depends predominantly on the time/current used for the welding, a maximum enhancement of ~124% is obtained for GNP-coated samples in comparison to that of the bare ones. Fracture surface analysis was performed by SEM, and it was observed that a mixture of both brittle and ductile fractures was the major cause of failure. Poorly joined weldments that exhibited interfacial failure and metal expulsion were also observed at lower and higher processing conditions, respectively. Dissimilar metal welding formed Al-Fe rich intermetallics ($FeAl_3$, Fe_2Al_5, and Fe_4Al_{13}), which enhanced some of the properties of the nano-composites formed in the nugget zone. Detailed microstructural characterization was carried out by light microscopy, AFM, SEM, TEM, XRD, and Raman spectroscopy. The enhancement of strength of the composite was done by numerous strengthening mechanisms as a result of the incorporation of GNPs. Micro-hardness investigation across the weld cross-section was carried out, and it was found that an enhancement in hardness due to the formation of intermetallics and graphene entrapment was reported.

Minimization of Orange Peel in Cr-Mn-N Austenitic Stainless steel for Usage in Utensils Application

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Cr-Mn-N Austenitic stainless steels (popularly known as 200 series) have evolved as a cost effective alternative for conventional 300 series SS for medium corrosive high strength application. High levels of carbon, manganese and nitrogen contributes to higher yield strength (about 30% higher than 18-8 chrome-nickel SS). The addition of copper reduces work hardening rate and improves ductility, which makes this grade a strong contender that finds suitability for deep drawing operation required for usage in hollowware application such as utensils.

In this study, an attempt has been made to reduce orange peel formation during deep drawing operations. Suitable modification in the process parameters were done to achieve optimum crystal grains in order to achieve the target LDR (1.9-2.1) without effective formation of orange peel after polishing of deep drawn components. These includes selective process parameters such as mechanical scale removal in hot rolled black coils, high percentage of cold reduction (>70%) in 20 Hi Sendzimir Mill (Z-mill) followed by controlled isothermal annealing in a continuous horizontal annealing furnace with reducing atmosphere.

Shimadzu AGS-X 100KN UTM machine was used for mechanical testing. Erichsen cupping test was carried out to verify the formability of the material. In-house laboratory scale deep drawing test followed by buffing operation was carried out to validate the presence of orange peel on surface. Microstructure of the developed product was analyzed for assessing grain size using optical microscope.

Keywords: Austenitic stainless steel, Cold reduction, Work Hardening, Continuous annealing, Erichsen Cupping.

Challenges in Development of Low Resistivity Cable Armour Quality Wire Rods at IISCO Steel Plant

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Steel wire armour (SWA) is an inextricable part of heavy-duty cables as it provides mechanical protection, which means the cable can withstand higher stresses. However, apart from strength, electrical resistivity is another crucial parameter of SWA owing to the fact that in case of short

circuit faults, the armour has to carry the short circuit current. The resistivity of the armour must be maintained within the designed value so that there is no excess temperature rise above the designed value and also there is no excess voltage rise. Properties of any material are broadly classified as extrinsic and intrinsic. Extrinsic properties are the properties that depend upon the dimensions of the material, whereas intrinsic properties are independent of the dimensions of the material; they depend upon the quality of the material. In the context of the cable armour quality (CAQ) steel grade, electrical resistance is an extrinsic property and electrical resistivity is an intrinsic property. Since the chemistry of any steel grade constitutes its quality, the electrical resistivity of CAQ steel is a function of its chemical composition. Based on this fact, the desired resistivity of CAQ wire rods is achieved by optimizing the chemistry of this grade with respect to silicon as electrical resistivity is affected predominantly by the silicon content of steel.
To tap the market of the CAQ steel grade, ISP undertook the development of this grade. The lean chemistry of this grade posed problems in its successful development. During the course of development, achieving low levels of carbon and silicon with adequate de-oxidation of liquid steel and the desired resistivity value in wire rods were major technological challenges. The present paper lays down the steps taken to overcome these challenges for the successful development of this grade

Improving Shaft Life by Controlling Metallurgical and Operating Parameters

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The gear box input shaft of skip car, which is used to carry limestone at the Lime Calcination Plant in an integrated steel plant, failed after 3 years of use. The shaft failed in torsional fatigue with features of high stress concentration and low nominal stress from the notched portion of the shaft. Chemical analysis showed that shaft is made of 18CrNiMo7 which is a case carburized grade. Metallurgical analysis revealed severe sulphide inclusions with a severity of 2.0 in thin and thick series as per ASTM E-45 and mixture of un-tempered martensite in the core. Un-tempered martensite is undesirable as it lowers the toughness of material and the presence of heavy inclusions deteriorates fatigue strength. Apart from metallurgical evaluation, electrical trend analysis and Finite Element Analysis was carried out. FEA report revealed the duty cycle achieved by the shaft is about 8.1 lac cycles. The fatigue duty cycle has also been affected by the circlip groove in the shaft. The calculated by the duty cycle, along with the combined effect of the two different causes is greater than one million cycles; i.e. about 5 years of life. Thus, failure at about

3 years is premature. Electrical analysis showed that the motor current shoots up to 138% while brake is engaged for 8 secs while starting, causing a very high alternate stress leading to fatigue crack initiation. Improper heat treatment, poor material quality, improper brake control leading to high torsional load on the input shaft and design weakness due to circlip grooves led to early fatigue in the shaft. To prevent this kind of failure, a proper quality assurance plan needs to be set up and brake control via drive relay output for the required starting torque is necessary. Design modification of input shaft by eliminating the circlip groove, along with changing of the shaft every 5 years to ensure zero interruptions due to failure during operation has also been recommended.

Keywords: Fatigue, Inclusion, Stress, Torsional Load.

Reduction in Coiling Temperature Variation on Rot of CM-60 Grade Steel

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Coiling temperature and the coil cooling rate in the finishing process in a hot rolling mill, needs to be accurately controlled to achieve high quality strips, with more uniform mechanical properties. The variation in temperature during the coil cooling affects the properties in some steel grades. In the present study, a hot rolled steel grade CM-60 (C, 0.60-0.65%, Mn, 0.82-0.85%), which showed variations in the temperature along the length of the coil was chosen for optimization, leading to down grading of some coils. The effect of process parameter of cooling rate and material behaviour on the run of table was analysed. The run out cooling table (ROT) cooling pattern was modified to achieve a more uniform temperature across the coil width. This optimization was done based on studying the phase transformation of the steel, using Differential Scanning Calorimetry (DSC), where the critical transformation temperature was determined. It was found that the Ar1 temperature of the steel during the hot rolling stage at which the secondary phase transformation takes place, influenced the variation in the coiling temperature. The cooling pattern in the ROT was changed by modifying the cooling in the last stage header, which resulted in a change of deep cooling at the final stage to a shallow cooling at the final header. Due to this, more uniform temperature across the coil width was realized resulting in a prime quality of the steel with good mechanical properties.

Keywords: Coiling Temperature, Phase transformation, Run out table and DSC

Elimination of Breakage in Grinding Balls of VPK 118 Grade

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Steel grinding balls are used in ball mills for crushing of coal, cement and building materials. JSW Steel limited Salem works supply the grinding ball grade as cast blooms to JSW Italy for manufacturing of steel balls. Recently ball manufacturing unit in Italy has faced frequent failure of balls due to breakage in their drop test with severe spalling and fractures. In general, DBT test, a common quality test procedure consists of dropping a ball from a height of 8 m onto a tube which is curved at the bottom (J-Tube) to evaluate the ball resistance to impact wear. The breakage in ball is of four types such as split to half by the pole, asymmetrical fracture, multiple fracture and excessive spalling. Grinding balls demands failure index value less than 5 from the DBT test. Recent supplies done from Salem unit are having higher failure index between 7 – 37. Improving the quality of grinding balls, demands process and product improvisations to restrict the failure index lesser than 5. Investigation and characterization on failed balls were analyzed on the aspects of microstructure, hardness, chemical composition processed from heats cast from two different cast sections. From the analysis, it could be understood that the balls which are having higher reduction resulting in fine grained steel fulfilled the required failure index of 5 in drop test. The grinding balls processed from higher cast section was found to perform satisfactorily in service.

Keywords: Drop Ball Test, Grinding Balls, Spalling, Failure Index

Quality Improvement of Bearing Grade Steel

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Bearing steel is one of the most demanding of the high-quality steel applications. Important criteria are cleanliness of the steel and the reduction of non-metallic inclusions – particles that could cause stresses and hence potential failure of the steel component. Demands on rolling bearing reliability and performance are continually increasing. Bearings are required to last longer and transmit ever higher loads often under difficult conditions. Quality requirement of bearing grades has undergone dimensional changes from RS3 to RS2 levels where, the inclusion density level of RS3 is 14 mm/dm^3 and that of RS2 is 2 mm/dm^3. Analysis of quality level in bearing grade indicates that, currently our products are meeting only RS3 quality levels and less than 50% of our products are only conforming to RS2 levels. By consistent achievement of RS2 levels, this grade can be used as import substitute in bearing segment. Customer requirements were analyzed and process parameters to achieve those customer requirements were derived through Quality Function Deployment (QFD) tool. Through the analyses, probable causes were identified and significant causes were derived through Hypothesis testing. The five significant causes were optimized through Design of Experiments (DOE). All the significant parameters were optimized and after successful trials, these parameters were standardized through revision of control plan and SOPs.

Keywords: Bearing, QFD, RS2, Inclusion density

Optimization of Chemistry and Process Parameters to Achieve Better Drawability of Wire Rod Coils for the Application of Inert Gas Welding Wires in Visakhapatnam Steel Plant

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Welding quality wire rod coils has high market demand with major application in welding electrode wire, CO_2 gas shielded welding wire and submerged arc welding wire as a filler metal. Welding quality wire rod coils can be manufactured from low carbon-high manganese billets with optimized rolling parameters. In Visakhapatnam steel plant, the chemistry of the same was optimized to maintain low carbon, high manganese, and low nitrogen in steel melting shop. The rolling parameters were optimized to enable retarded cooling by maintaining low mill speed, low laying head temperature and low stelmor speed. The rolling parameters facilitates to form non-adherent scale and to obtain desired microstructure for achieving suitable mechanical properties for the end application. Mechanical testing like tensile test and torsion test was carried out. The mechanical testing of the wire rod coils was done throughout one loop of the coil to ensure uniformity and no deviation in the mechanical property. The customer feedback was taken. The market demand and sales of Vizag CO_2 wire rod coils help to earn revenue and increases the market share of Visakhapatnam steel plant.

Keywords: Welding wire rod coils, Vizag CO_2, retarded cooling, revenue.

Head Hardening of Jindal Steel Rails

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The recent trends in railway transportation have been directed towards the development of heavier axle load and higher speed, thereby subjecting the rail steel to increasingly severe operating conditions. A major objective in the development of new rail materials is improving their wear performance. Head-hardened rails in combination with an appropriate maintenance strategy can contribute to a significant reduction in total life-cycle costs. In line with the Government's thrust on 'Make in India', JSPL has successfully installed a Head Hardened Rails system. JSPL being the only producer of Head Hardened Rails in the country is poised to play an important role in the growth of India's rail infrastructure. The installation of the India's first application of a break-through technology for rail head hardening was started at Jindal steel and Power Ltd, Raigarh.
To aid the optimisation of the unit installed at the rail rolling mill of JSPL "Rail Head Hardening prototype" system was designed. A similar controlled cooling exercise was undertaken on the rail cooling rig with extensive research followed through a lot of trials and applied various customized cooling protocols to obtain desired microstructure and hardness distribution across the rail head, with a high degree of accuracy and operating flexibility. This paper illustrates the key concepts of Rail Cooling Rig Design and experimentally investigates the effects and interactions of the major factors controlling the cooling process.

Keywords: Head hardened rails, Make in India, JSPL, heat treatment Prototype, hardness

Effect of Hot Rolling Process parameters on Banded Scale in HR Strip

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TSCR Plant, TSL Jamshedpur produces deep drawing and HSLA Steel grade for various automotive customers for applications like Long and cross member, Wheel Rim and Disc and support structures. where surface appearance is critically evaluated. Customers were facing a chronic issue of banded rolled-in scale, which lead to rejection at plant and Claim. Data stratification on the occurrence of defect was carried out at rolling plant to measure the problem and DMAIC way of problem solving was applied. Several QC tools were applied with the data generated on various process affecting banded rolled-in scale like rolling temperatures, draft in mill stands, lubrication & roll wear etc. Such data analysis showed the impact of healing-peeling involved in work roll oxidation on surface defect generation. Technical understanding from the outcome of this work was applied practically to bring down the defect occurrence in hot rolling process from 0.18% in FY’19 to 0.08% in FY’20 and to 0.05% in FY’21 with zero claim on account of the defect in FY’21. Further, supply of defect free material to customers continued to be key in customer satisfaction and engaged relationship.

Non-Ferrous Metals

KEYNOTE LECTURES

Developments in Extractive Metallurgy of Titanium and Magnesium

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Titanium metal has emerged as an important structural material for a wide range of applications in aerospace, chemical and petrochemical, power generation, automotive and medical industries. Extraction of titanium metal mainly takes place by the Kroll process of high temperature magnesium reduction of titanium tetrachloride ($TiCl_4$) in which anhydrous MgCh is generated as reaction by-product. In an integrated titanium production plant, recycling of magnesium metal by fused salt electrolysis of MgCh assumes greater importance, as it ensures raw material availability for captive consumption and improves economics of titanium sponge production. DMRL has carried out extensive R& D in both the Kroll process and fused salt electrolysis of magnesium chloride. While a 500 MT/year titanium sponge plant was established at KMML, Chavara, Kerala with DMRL technology, two magnesium pilot project of 70 MT/year capacity employing the DMRL 'technical knowhow' are seriously being pursued. The presentation brings out technological developments that have been taken place at DMRL and highlights current status of the activities,
The presentation also brings out several developments that have been taken place in the extraction metallurgy of titanium and magnesium in the world, over the years for evolving energy and cost improvements in the extraction processes.

Keywords: Extraction, titanium, magnesium, developments, status in India

Translational Materials Research in Energy Storage Technologies

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The necessity of batteries is increasing due to the target set by the Government of India that 30% of the vehicles produced in India should be electric vehicles by 2030. Li-ion batteries are the key storage systems used in EVs due to their capability of storing high energy density and fast charging and discharging characteristics. While the demand is huge, India is totally dependent on imports of these Li-ion batteries. While government is encouraging establishment of Li-ion battery plants, the battery production in India is yet to pick-up. This is largely due to lack of indigenous technologies, which are essential to make the final batteries are cheaper or on par with the imported batteries. Material cost of a Li ion battery is ~ 60% of the overall cost of the Li-ion battery. While it difficult to compete in equipment manufacturing immediately, indigenous production of materials is essential and possible to reduce the import dependence of li-ion batteries. Alternatively, it is need of the hour to look into non-lithium based storage technologies (e.g., Na-ion batteries and supercapacitors) which are already being commercialized globally.

In line with the above requirement and the 'Atmanirbhar Bharat Abhiyan' or 'Self-Reliant India Mission', ARCI had developed indigenous technologies for the production of two key battery grade electrode materials, Lithium Iron Phosphate (LFP) cathode and Lithium Titanate (LTO) anode powders for LIB. The unique know-how developed by ARCI involves solid state synthesis of LFP/LTO in a single step and these materials have been validated in coin cell and cylindrical cell configurations and they show promising electrochemical properties in terms of high discharge capacity, cyclic stability and excellent rate capability on par with the performances of commercial materials. Recently, LFP technology is transferred to one of the Indian companies, and the LTO technology is ready for transfer.

ARCI has also embarked on the fields of supercapacitors (SC) and Na ion-batteries and developed graphene-like activated porous carbon by a low-cost chemical activation process from petroleum coke (pet coke) and Ni-Mn based layered metal oxide and Prussian blue analogue materials for these emerging storage technologies. ARCI has demonstrated, for the first time in India, a 1200 F super capacitor made from the above said pet coke, which is a requirement in EVs for regenerative breaking and enhancing the battery performance when used in hybrid mode. Fundamental challenges in technology development, addressing those challenges and technology commercialization aspects will be discussed.

Additive Manufacturing of Non-Ferrous Alloys – Prospects and Challenges

Govind
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Additive manufacturing is a layer-by-layer material deposition method to build 3D part. Material can be in the form of powder, wire or sheet and energy source can be laser, electron beam, electric arc, plasma, ultrasonic etc. 3D model of the component to be printed is first divided into number of slices and metal is deposited as per the geometry in each slice. Fully dense components could be realized in various alloys using optimized process parameters. One of the most promising AM process for complex components is Powder Bed Fusion (PBF) or Selective Laser Melting (SLM) wherein powder feed stock is spread layer-by-layer and melting is carried out by laser source. SLM process involves melting of about 60-200 μm thick layer at a scan speed of 600 – 2000 mm/s.

It leads to very high cooling rates (10^4-10^6 K/s) as well as very high thermal gradients. Microstructures so produced are very fine due rapid solidification which is inherent in the process. Present study is carried out on Al-alloy AlSi10Mg and IN718 which are processed through PBF process. AM processed samples were subjected to different heat treatment cycles and microstructure and properties were characterized. It is noted that coupons printed with optimized process parameters can provide properties similar to wrought alloys. Different combinations of strength and ductility can be obtained with varying heat treatment cycle. Extended solid solubility too is also found in the Al-Si system.

The SLM processed AlSi10Mg alloys result in a fine cellular microstructure of silicon (Si) in Al matrix. The sample shows fine equiaxed grains in the meltpool core and four different regions on the boundary. These regions are fine cellular region, coarse region, intermediate region and heat effected zone. Total strength of SLM materials were integral of number of melt pool, melted and re-melted region and boundary region. Stress relieved and as fabricated (AF) samples were subjected to standard T6 heat treatment. Stress relieved samples exhibited higher ductility than as-fabricated samples. Paper discusses details of the properties achieved and challenges faced.

ORAL PRESENTATIONS

Non-conventional Reductive Acid Leaching of Manganese from Low Grade Ore using Corn Husk

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Manganese is known to be mostly available in the form of pyrolusite (MnO_2) in form of Mn (IV) naturally. To get the Mn (II) in the soluble form in the leach liquor reductant is used to reduce the aqueous insoluble Mn (IV) to aqueous soluble Mn (II) form. The conventional acidic reduction leaching process involves reduction through charcoal, SO_2 or organic reductants. But in this study the sulphuric acid-based reduction leaching of Mn (IV) to Mn (II) has been performed with corn cob as the reductant in room temperature and with intermittent stirring. The leaching efficiency is 59.23 % in 30 days with 7% (w/w) reductant (corn husk) and with increase in reductant amount to 15% (w/w) the leaching efficiency increased to 84.04% in 30 days.

Keywords: Manganese, Corn husk, Reductive leaching

Development of Bioleaching in Nickel Recovery from Laterite Ores

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The demand for nickel and cobalt are extremely met through imports in India. The annual requirement of nickel has already reached 20,000 tonne per year and likely to be doubled by the turn of this century. Different sources of nickel are usually the nickel sulfide and laterite ores but unfortunately there is no known nickel sulfide ore deposit in India. Therefore greater efforts are being made to extract nickel from different low-grade laterite ores. Worldwide, about 85% of nickel reserve is associated with laterite ores. It is strongly believed that the nickel production in the near future will be dominated by laterite ores. A reserve of about 71 million tonne of laterite ores averaging 0.85% nickel has been estimated by the Geological Survey of India. But from international standard, they don not fall into the category of ore because of very low tenures of metal within them. There is a huge reserve of laterite ores which are estimated to be 231.36 million tonne in the Sukinda valley of Odisha, India with a nickel content of 0.15-1.2% along with trace amount of cobalt and manganese. Therefore, there is an urgent need of setting up a processing plant of laterite ores in the Odisha region, which will definitely reduce the nickel import of the nation. Processing the laterite ores is not economical using the conventional techniques i.e. pyrometallurgy and hydrometallurgy. Bioleaching of the laterite ores is a potential alternative to the conventional techniques. However, the research related to bioleaching of laterite nickel ores is not adequate to draw a conclusion on setting up the processing plants.

Keywords: Bioleaching, Laterite ores, Sukinda Valley, Autotrophs, Heterotrophs

Achieving Benchmark Current Efficiency in Zinc Hydro Smelter Cell House

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Hindustan Zinc's operations comprise lead-zinc mines, hydrometallurgical zinc smelters, lead smelters, pyro metallurgical lead-zinc smelter as well as sulphuric acid and captive power plants in northwest India. Total metal production capacity is 890,000 MT of zinc and 205,000 MT of lead. We have facilities located in Rampura Agucha, Chanderiya, Dariba, Kayad and Zawar in the state of Rajasthan, along with zinc-lead processing and refining facilities and a silver refinery at Panthnagar in the state of Uttarakhand. Traditionally, hydrometallurgy is emphasized for metals extraction from ores. Hydrometallurgical processing may be used for the following purposes. Production of pure solutions from which high purity metals can be produced by electrolysis, e.g., copper, zinc, nickel, gold, and silver.

In early 2015, it became apparent that with changing concentrate feeds, the impurity load projected for Hindustan Zinc starting in 2017 and beyond would quadruple and overwhelm the current Leaching-Electrolysis process. Effect of process parameters at Leaching-Electrolysis for the electrodeposition of zinc has been carried out & implemented. Influence of current density on the deposition process was also investigated. The efficiency of zinc deposition was affected by the temperature of cells, Gypsum section pH, Acidity of electrolyte & neutral leaching pH etc. There are many elements which are detrimental to the current efficiency in the electrolysis of zinc sulphate.

In electrolysis process, amount of electricity required to deposit the zinc is described by Faraday's

law. The actual production of zinc metal by theoretical production as per calculation is known as current efficiency. Higher current efficiency will reduce my power consumption in cell house as well as contributes in reduction of carbon footprint.
Increasing of 1% current efficiency will lead to increasing 7.7 MT zinc ingot production per day and saving of 35 units of power consumption amounting 2.26$/MT.

Production of Chemical Manganese Dioxide from Low Grade Manganese Ore

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Manganese is considered as strategically important and indispensable metal because of its huge application in many fields, such as steel production, non-ferrous metallurgy, battery and chemicals. In the recent years, the world annual demand for manganese is increasing rapidly due to continuous increase in steel and battery production in developing countries. Increasing demand for this metal, owing to fast depletion of high-grade ore and therefore attention has to be devoted for the improvement of manganese recovery from low grade manganese ore or secondary resource. Iron and silica is considered as major impurities presents in the low grade manganese ore. Therefore, the present article explores the possibility of extracting manganese from low grade manganese ore containing 53.40% MnO_2, 16.92% Fe_2O_3 and 12.51% SiO_2 as major constituents with minimum dissolution of iron and silica. Therefore, a combined ammonium sulphate roasting-water leaching process was developed to recover manganese as sulphate salt with complete rejection of iron as iron oxide in the residue. Various process parameters such as ammonium sulphate dosage, roasting temperature and time were studied and optimized. At roasting temperature of 600 °C, the percent leaching of manganese is > 98% with <1% of iron in the leach solution. The leached solution is further purified and precipitated as manganese carbonate (>98%) in the presence of ammonium carbonate. The precipitate was dried and calcined at 350 °C to produce chemical manganese dioxide (CMD). The products were characterized by chemical analysis, XRD and SEM.

Modelling of Heap Leaching

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Heap leaching is being studied with renewed interest as many ores are depleting in their metal content. Moreover, it is more economical and environmentally friendly than other routes of extraction of metals such as pyrometallurgy. It is widely used for lean ore of Cu, Ni, Au etc., for the extraction of metals. The liquid flow behaviour is the most important parameter to decide the efficiency of the process as this affects the extraction of metals. Therefore, many researchers have studied liquid behaviour using experimental and mathematical models. In the latter approach, the fluid is considered as a continuum in various methods. However, it is evident from heap leaching experiments that liquid flow is in rivulet/droplet form due to very low flow rate and sometime non-wetting characteristics of ores. So, modelling efforts, treating the liquid as a continuum may not give the desired results. Moreover, the method is also dependent on experimental inputs such as the permeability of the bed. Here, we propose a novel approach of modelling of liquid considering it as discrete in nature. It is a fully deterministic model to predict the liquid flow and is based on Discrete Flow Theory (DFT) proposed by Gupta et al. (1997) (Metall Mater Trans B Process Metall Mater Process Sci. 1997;28(4):597-604). Using this model, the liquid behaviour is studied in a heap by considering various size of particles and contact area between the liquid and solid is evaluated which determines the efficiency of the process. Mono size and mixed size particle heaps are considered in this study. The effect of liquid flow rate on heap efficiency has also been studied.

Extraction of Copper from Chalcopyrite Concentrates via Surfactant Assisted Chlorination Process

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Chalcopyrite is one of the most refractory and abundant ores of the copper. The numerous processing routes have been proposed to extract copper from this ore. Atmospheric leaching with chlorine gas is found to be more effective in comparison to other atmospheric leaching processes. However, the challenge is to overcome the problem of slow leaching kinetics due to passivation encountered at high strength solution in this system. In this study, surfactant mediated chlorine leaching of typical chalcopyrite ore has been tried to overcome the passivation issue by dispersing the S^o layer. Commercially available reagent such as chlorinated alkene has been used for the first time as a 'S^o' dispersant in this study. In absence of the surfactant, about 70 % Cu could be dissolved from the chalcopyrite ore, while addition of 2% (v/v) chloro-alkene yielded more than 95 % recovery of Cu. This leaching method appears to be very promising for further up-scaling. The effect of gas flow rate, temperature, solid-liquid ratio, concentration of surfactant, etc on rate

of copper dissolution has been studied in detail.

Keywords: Hydrometallurgy Chalcopyrite, chlorination, surfactant

Preparation of Neodymium Iron Boron Alloy ($Nd_2Fe_{14}B$) by Molten Salt Aided Metallothermic Reduction Diffusion Technique

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The present investigation focuses on the preparation of $Nd_2Fe_{14}B$ alloy by Molten Salt Aided Metallothermic Reduction Diffusion (R-D) process with low energy consumption. Oxide precursors of neodymium (Nd), iron (Fe) and boron (B) were used as the precursor materials. Eutectic chloride mixture was used as the molten flux during the R-D process. Scrap magnalium powder was used as the reductant. The thermal reduction was carried out at 850 ˚C for 5 hours in inert atmosphere. After the completion of reaction, the contents were purified by treating with dilute acid followed by suitable solvent.
Thermal analysis was performed to assess the dissociation and decomposition reactions with respect to temperature. The phase purity and the elemental composition of the alloy were determined by XRD and EDAX analyses. The morphological features of the prepared powders were examined by SEM.
From this study, it has been concluded that $Nd_2Fe_{14}B$ alloy can be prepared with an appreciable purity by Molten Salt Aided Metallothermic Reduction Diffusion process. This process is an environmentally friendly and economical process to produce $Nd_2Fe_{14}B$ powder using scrap magnalium alloy as the reductant.

Effect of Diffusion Pt-Aluminide and Overlay NiCoCrAlY Bond Coats on Tensile Properties of DS Ni-base Superalloy CM247LC

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Ni-base superalloy components such as blades and vanes are used in advanced gas turbine engines. These components are typically applied with a diffusion Pt-Aluminide (Pt-Al) or an air plasma sprayed (APS) overlay NiCoCrAlY coating for high temperature oxidation protection. These coatings are constituted of brittle β-NiAl phase and are known to degrade the mechanical properties of the substrate superalloy. High temperature oxidation exposure of the coated parts can also lead to further degradation of substrate properties.

The present study examines the effect of an oxidation resistant coating on the tensile properties of CM-247LC Ni-base superalloy. The properties of the superalloy have been evaluated at 870°C in uncoated, Pt-Al and APS NiCoCrAlY coated conditions. The yield strength (YS) and ultimate tensile strength (UTS) of the uncoated alloy were 843 and 947 MPa, respectively. The corresponding values for Pt-Al coated alloy were 870 and 930 MPa, respectively. The same for NiCoCrAlY coated alloy were 699 and 797 MPa, respectively. The presence of Pt-Al coating did not affect the strength properties. However, NiCoCrAlY coating caused a decrease in strength of the substrate alloy by about 17%. Application of these coatings did not affect the ductility of the superalloy.

After thermal exposure for 150 h at 1100 °C in air, the YS and UTS of the uncoated alloy were 819 and 854 MPa, respectively. The corresponding strength properties of Pt-Al coated superalloy were similar to those of the uncoated alloy. In case of APS NiCoCrAlY, however, a decrease in strength by about 11% was observed for the same exposure at high temperature. Degradation in alloy ductility was not observed in case of both the coatings because of the beneficial effect of the coating in preventing oxidation-induced surface damage.

Keywords: coatings, tensile properties, cyclic oxidation

Modelling Microstructural Evolution during Homogenization of AA3003 Aluminium Alloys

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Homogenization of cast AA3XXX aluminium alloys are carried out to reduce the microsegregation of Mn and break the continuous network of eutectic intermetallic phases. The deformation behaviour of the homogenized slab during subsequent downstream operations, is influenced by the microstructure at the end of homogenization. During homogenization of AA3003, fine dispersoids are precipitated and the eutectic Al_6(Fe,Mn) phase is transformed into α-Al(Fe,Mn)Si. A computational framework is developed to predict the kinetics of dispersoid evolution and phase transformation during homogenization. The dispersoid model utilizes a Euler-like multi-class approach to predict the precipitation kinetics in terms of number density, size distribution and volume fraction of dispersoids for a given thermal profile. OpenCalphad is used to extract the equilibrium matrix and dispersoid composition for determining the driving force for precipitation. The phase transformation model predicts the kinetics of Al_6(Fe,Mn) and α-Al(Fe,Mn)Si phase transformation for the given thermal profile. The integrated computational framework is used to determine the homogenization cycle to achieve the desired microstructural characteristics. The model results are validated with benchmarked literature data and analysis of the results is presented.

Multiscale Simulations of Deformation Behaviour of Ni based Alloy 690 Considering Grain Boundary Effect

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Grain boundaries in metals play an important role in governing the plastic deformation behaviour. Modelling their effects demands a multiscale description of the associated phenomena. Therefore, this work presents a two-scale atomistic and crystal plasticity finite element modelling approach for predicting the deformation behaviour of Ni based alloy 690. Atomistic simulations are utilized to quantify the activation energy parameters associated with nucleation of partial dislocations from Σ3 and Σ9 grain boundaries. These parameters are then passed directly to higher scale crystal plasticity model based on transition state theory. At this level of modelling, grain boundaries are explicitly modelled by providing finite thickness and are differentiated from the bulk grains by prescribing distinct activation parameters extracted from lower scale atomistic simulations. The proposed method is finally assessed by predicting the uniaxial tensile behaviour of alloy 690 and validating it from the available experiments.

Influence of Microstructure and Texture on the *in-vitro* Bio-corrosion Behaviour of Hard-plate Hot Forged Mg-4Zn-0.5Ca-0.16Mn (wt. %) Alloy

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In this work, the implication of microstructural and textural evolution, realized through a novel hard-plate hot forging at various temperatures (523 K, 573 K, and 623 K), on corrosion behavior in a Mg-4Zn-0.5Ca-0.16Mn alloy are critically examined. The *in-vitro* bio-corrosion behavior of all the forged specimens have been evaluated through the immersion test, polarization test, and

EIS measurement. The hard-plate hot forging treatment at an optimized temperature of 573 K was found to be effective in grain refinement through the PSN-assisted dynamic recrystallization, uniform distribution of second phase precipitates, and inducing strong basal texture as compared to the other two forging temperatures. It has been observed that both second phase particles-matrix interfaces and grain boundaries have acted as a galvanic couple with the Mg matrix and provided an effective site for corrosion initiation and subsequent corrosion product formation during exposure of the specimens in the KBM solution. Due to the distinct microstructural advantages of the AF573 specimen, a more uniform, compact, and protective corrosion product layer has been developed on this specimen's surface, which consisted of insoluble components of $CaCO_3$, $Ca_3(PO_4)_2$, $Mg(OH)_2$ and hydroxyapatite. Such a protective corrosion product layer, as well as strong basal texture, has significantly reduced the pH change, hydrogen evolution, and corrosion rate during the long-term immersion test. The outstanding corrosion resistance of the studied alloy, in its optimized processing condition, is expected to make it a suitable biodegradable implant material for potential orthopedic applications.

Study on Oxidation Kinetics of Uranium & U-10Mo Alloy in Air

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The isothermal oxidation behaviours of metallic Uranium (U) and U-10wt% Molybdenum (U-10Mo) were studied by X-ray diffraction (XRD) and Thermogravimetric (TG) techniques in the temperature ranges of 473-673 K and 773-873 K, respectively. Dynamic (non-isothermal) TG plot was used to estimate the onset of breakaway oxidation and select the temperature regime for isothermal studies. Isothermal oxidation was used to study the kinetics of the oxidation reaction. It was found from XRD study that Uranium was completely oxidised to U_3O_8 at 673 K after 3 h whereas in U-10Mo even at 848 K, □-U & UO_{2+x} phases were present along with U_3O_8 at the end of 3 h. The activation energy for oxidation of U–10 wt% Mo was determined to be 120 kJ/mol in the temperature range of 773-873 K and that of Uranium was 90 kJ/mol in the temperature range of 523-673K. The oxidation resistance of U-10Mo could be attributed to both (i) isotropic □-phase (bcc) of U-10Mo resulting in stable oxide film compared to that formed on □-phase (orthorhombic) Uranium and (ii) lattice strain due to substitution of Mo in the oxide lattice which in turn retards the diffusion of oxygen through the oxide film.

Keywords: U-Mo alloy, Kinetics, Oxidation, Thermogravimetric analysis, activation energy

Direct Energy Deposition of a Low Modulus TNZT Alloy for Biomedical Applications

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Additive manufacturing of metals and alloys offers a unique route for preparing customized implants. Direct energy deposition (DED) is one of the additive manufacturing processes that can yield patient-specific implants. TNZT, a β-type titanium alloy, exhibits a combination of excellent biocompatibility, high strength, good corrosion resistance and low elastic modulus. Additive manufacturing of TNZT by DED has received little attention in the scientific literature. Gas atomized Ti-34Nb-7Zr-5Ta powder was used for DED in this study. Design of experiment (DOE) was performed by varying key parameters such as power, scanning speed, rotation between layers and powder flow rate. Parameter optimization study was performed and at optimized parameters nearly dense component was produced. Defects such as lack of fusion, cracks and spherical porosity was observed in several conditions. By increasing the power, lack of fusion was completely removed, and nearly dense components were produced. Qualification of these dense components were studied through microstructural analysis, texture and mechanical behaviour study. X-ray diffraction analysis was carried out for structural characterization, and it showed the presence of β phase only. Micro-hardness measurement was done, and it did not show anisotropy along the build direction. However, small change in micro-hardness between two dense conditions was observed. Increase in power during fabrication of components resulted into stronger texture formation along build direction. These results have important implications for preparing the next generation of orthopedic implants.

Effect of Ageing on Coarsening Kinetics, Solute Partitioning, Misfit and Low Cycle Fatigue Properties in Haynes 282

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Elemental partitioning across the precipitate/matrix interface controls the kinetics of precipitate evolution, during growth and coarsening. In the present study, coarsening behaviour of γ' precipitate for various ageing temperatures at 650 °C and 760 °C and ageing times (1-9 days) have

been investigated. We present the first integrated analysis of evolution of both the aspects of microstructure, i.e., the size of nano-scale, ordered, coherent γ′ precipitates as well as the lattice misfit at the interface, in light of elemental partitioning, applied to a Ni-based superalloy, Haynes 282. In this work, experimental analyses by APT, TEM, and XRD are combined with thermo-kinetic modelling using ThermoCalc and TC-PRISMA. For the first time, rate-controlling elements for growth and coarsening stages of γ′ precipitate have been identified: Ti diffusion into γ′ precipitate controls the growth rate; coarsening kinetics is controlled by the diffusion of Mo into the matrix. For the coarsening kinetics, unlike most of the recent literature, we have used the thermodynamic parameter corresponding to the non-dilute, non-ideal γ solid solution phase in the modified LSW rate equation. This approach provides a much realistic prediction, as Ni-based superalloys show significant deviation from ideality. Misfit is positive and found to decrease with ageing time in the present alloy.

Also, low cycle fatigue behavior of various ageing conditions at high temperatures (650 °C and 760 °C) is presented for the first time, emphasizing the microstructural effects. While 650 °C, 9 days ageing condition showed primarily signatures of γ′ shearing, 760 °C, 9 days ageing condition showed primarily the Orowan mechanism of deformation. Promising mechanical properties have been achieved by varying ageing conditions. These results in Ni-base superalloys enable tuning the microstructure of these alloys and widening the alloy spectrum for designing improved high-temperature alloys.

Keywords: Coarsening kinetics, Solute partitioning, Haynes 282, Atom probe tomography, Fatigue

Mechanical Behavior of Ti-Ni-Fe & Ti-Fe-Co based B2 Pseudo Binary Intermetallic at Different Length Scales

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Intermetallic compounds have long been known to possess attractive physical, chemical electrical, magnetic and superior mechanical properties. Long range order in these intermetallic produces stronger bonding and closer packing between atoms which restricts the atomic mobility and generally leads to slower diffusion process making them usable at high temperature applications. However, their enormous potential to improve engineering performance remains largely unused because of their low deformability at room temperature. Deformation in intermetallics is achieved

by contrivances, such as using materials that deviate from stoichiometry and have metastable disordered structure, adding dopants such as boron or by phase transformations. B2 structured intermetallics deform to different extent: polycrystalline NiAl (aluminides) elongates up to 1-2 % before fracture; AuZn and ternary ZrCoNi elongate up to (6-8) % & 18 %, respectively. Whilst binary B2 compounds have been explored a lot, only a few pseudo-binary B2 intermetallics have been investigated. This work focuses on Ti-based pseudo-binary intermetallic such as Ti-Ni-Fe and Ti-Fe-Co. Microstructural and mechanical characterization have been carried out using SEM, XRD, EBSD, bulk compression, micro-indentation and nano-indentation. It is attributed that the variation in properties is not only due to the composition but also due to a cumulative effect of texture, stoichiometry leading to the presence of point defects, such as antisite, grain size and site preference energy due to ternary substitution.

Effect of Pre-Weld Heat Treatment conditions on Mechanical Properties of Inconel x 750 Alloy Weldments

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Inconel X750 is a precipitation-hardenable nickel-chromium alloy with high strength and oxidation resistance at elevated temperatures which makes it ideally suitable for gas turbines, jet engine parts and rocket-engine thrust chambers. Many of the parts in these applications are realized through welding route because of its complex geometrical requirements. Being a precipitation hardenable alloy the heat treatment cycle of the alloy prior to welding plays a major role on the mechanical properties of the weldment. However, because of hardware limitations in certain cases post weld heat treatments may not be possible and the weldment may have to be used in as welded condition.

This study addressed the effect of pre weld heat treatment condition on the fusion zone microstructure and the mechanical properties of tungsten inert gas (TIG) weldments of Inconel X750 with solid solution strengthened filler wire in as welded condition without post weld heat treatment. Comparative studies on the microstructure and mechanical properties have been made on the weldments in the as welded condition with pre-weld heat treatment conditions of solution treated and solution treated and direct aged conditions for the parent metal. The mechanical properties were evaluated both at room temperature and high temperature conditions. The resulting weldments were also examined to determine the resulting material hardness and observed with optical microscopy and scanning electron microscopy in the fusion zone and heat-affected zone.

The study revealed higher ultimate tensile strength and yield strength for weldments welded in direct aged condition as compared to solution treated condition both in ambient temperature and

elevated temperature. However, in both the cases the failure location was on the weld. It was also inferred that the weldments in solution treated condition underwent more elongation as compared to the direct aged weldments.

Keywords: Inconel X 750, Pre weld heat treatment, Mechanical properties, Microstructure

Study on Role of RE Elements Addition in Deformation Behaviour of Magnesium Alloy

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There is a surge in demand for magnesium (Mg) alloys for different applications in aerospace, automotive, electronics and biomedical applications. Low strength and poor formability at room temperature deters the wider applications of wrought magnesium alloy. Low formability is caused by strong deformation textures (basal texture) and highly anisotropic behaviour of wrought alloys. This has prompted the investigation of different alloying elements and processing effects on Mg to get more enhanced properties. A possible solution to these problems is addition of rare earth (RE) elements in Magnesium. Mg-RE based alloys are increasingly being studied owing to the formation of highly stable strengthening phases, activation of additional deformation modes and enhancement in mechanical properties.
Past studies have shown alloying each RE in higher quantities to the Mg system gives unique behaviour to the cast alloy. The age hardening response of alloy Mg-10Gd (wt%) is good and can be further enhanced by the tertiary alloying. Dysprosium (Dy) is an important heavy RE alloying element and its influence on the strengthening mechanisms of Mg-10Gd (wt%) is unexplored. The present study deal with the investigation of microstructural characterization and deformation behaviour of a stir casted as-cast, solutionized and wrought Mg-10Gd-xDy alloys (x=0, 2, 5 wt%). In this study we have shown the difference in mechanical properties of different alloy with respect to alloying in both as-cast and rolled samples. Microstructural Characterization of sample before and after rolling has been done using EBSD. The distribution of second phase has been further studied using SEM.

Keywords: Mg-RE alloy, Solutionizing, Rolling, Mechanical Testing, EBSD

Effect of Welding Process on Microstructure, Mechanical Properties and Corrosion Behaviour of AA2519 Al-Alloy

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AA2519 is high strength aluminium alloy, extensively used in fabrication of amphibian assault vehicles and light weight combat vehicles due to its high mechanical properties, ballistic resistance and strength to weight ratio. Inspite of its better properties compared to other alloys, there are some problems due to welding. Formation of oxide layers, solidification cracking and porosity are the major problems raised during the welding of this alloy. In view of the above, present work is planned to investigate the effect of welding processes on microstructural changes, corrosion behavior and mechanical properties of AA2519 Al-alloy. Electron beam welding (EBW) and Friction Stir Welding (FSW) were used in the present work to weld 10mm thick plates of AA2519 Al-alloys at T87 temper condition. Microstructure and hardness in as welded condition were studied. Potentio-dynamic polarization tests were conducted in aqueous solution of 3.5% NaCl aerated environment to study the pitting corrosion behavior. Exfoliation corrosion studies are carried out for various time lapses with EXCO solution. Results of the work shown good correlation of corrosion resistance and mechanical properties of AA2519 FS welds when compared to that of EBW welds. Insulation paths of galvanic cell formation between Al_2Cu and α-Al matrix are provided due to the presence of undissolved additional strengthening precipitates like Al_2CuMg, Al_3Zr and Al_3Ti. Better combination of hardness and corrosion resistance was observed in friction stir welds of AA2519 and is attributed to the presence of trace alloying elements of Zr and Ti when compared to that of AA2219 Al-Cu alloy.

Keywords: EBW welds, FS welds, Ballistic resistance, Galvanic cell, Insulation paths, Strengthening precipitates

A Study on Strength and Microstructure Properties of Welded Russian Equivalents of Rene 41 and 12-10PH Steel

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Dissimilar metal welding is often required when there is a change in mechanical properties and performance of the components. This type of welding is often used in high temperature application of jet and liquid rocket engines. This study has been carried out with the Russian equivalents of Rene 41 and 12-10PH steel. There are minor changes in the composition from their equivalents. The exact details of the material composition are not available. Rene 41 is a precipitation-hardened nickel-base superalloy which is mainly used in jet engine, missile components and rocket liquid engines which require high strength at higher temperatures. The precipitation hardened steels are used where high strength and resistance to corrosion and oxidation are desired. Due to high thickness of the joint, there will be significant dilution. Literature survey of various sources on dissimilar welding has revealed that no study has been reported regarding the dissimilar welding between these two materials. Hence, an effort has been made to study the strength and microstructure of dissimilar welding between these two materials.

In the present research work, 14 mm thick dissimilar metal welding between Russian equivalents of Rene41 in solution treated and aged condition and Russian equivalent of 12-10PH steel using manual gas tungsten arc welding has been performed to assess the microstructure, tensile, ductility and microhardness properties of the welds. The welding was carried out with Russian equivalent of Inconel 625 filler wire. The complete penetration was achieved using multi pass welding. Good cleaning procedures were used to prevent contamination of welds and HAZ. The tensile tests were carried out at the room temperature and at 840 K. The average ultimate tensile strength of the weld at room temperature was found to be 738 MPa and failure happened in weld. The average ultimate tensile strength of the weld at 840 K was found to be 447 MPa and failure happened in HAZ on steel side. The percentage elongation at room temperature and high temperatures indicated the ductile failure. The average micro hardness of the weld was observed to be 250 HV. The ductility of the weld was analysed using bend test. Microstructure study showed that the Russian equivalent of Rene 41 is free from HAZ microfissures.

Keywords: Rene41, PH-Steels, GTAW, High temperature application, Mechanical properties, Microstructure

Effects of *in situ* Al_3Ti Composite Particles on Aluminium Foams

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Closed-cell aluminium metal foams are an important class of lightweight engineering materials with applications in shock absorbers, thermal and acoustic insulation. The properties of these materials are dependent on the stability during the solidification process that decides the pore morphology and its distribution. An efficient way of stabilizing the foam is by adding ceramic particles which control the viscosity and surface tension of the melt. Al_3Ti particles are a good candidate for aluminium melt stabilization due to their good wettability. However, there is limited literature on the influence of Al_3Ti particles on aluminium foam formed through the liquid melt process. Hence, the present study deals with the fabrication and characterization of Al_3Ti/Al6061 *in situ* composite foam via liquid metallurgy. The cell structure of the *in situ* composite foams was analyzed quantitatively in 3D using X-ray tomography. The segmented 3D images are used for measuring the pore morphology and its size, and spatial distribution. The study revealed that the presence of *in situ* Al_3Ti composite particles not only changes the average pore size but also has a pronounced impact on its density and distribution.

Development of High Entropy Nano Slag Particulates Reinforced AA7075 Nano Composites

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In recent years aluminium metal matrix composites (AMMCs) are extensively used in industrial applications like automobile and aerospace due to its low density, high specific strength and low thermal expansion. In AMMC's the reinforcement materials like SiC, SiO_2, Al_2O_3, B_4C, TiC, TiO_2, TiB_2 are used as a most preferred ceramic reinforcements due to their high specific strength, high stiffness, and wear resistance. However, brittleness is the major drawback if added higher amounts

of these ceramic particles in given AMMCs; also cost of these reinforcements are one of the major bottlenecks. In the present investigation studies have been carried out on addition of industrial solid waste of ferro alloy slag particles as reinforcement in AA 7075 alloy. Nano size particles are prepared by high energy ball milling method. Prepared nano particles are characterized by XRD, SEM-EDS and TG-DTA for its size and other properties evaluation. Nano size slag particles revealed enhanced entropy values. Hence, nano size with high entropy ferro alloy slag particles are added to evaluate the size effects in the given alloy matrix. Metal matrix nano composites (MMNCs) are made by stir casting technique. Prepared nano composites are evaluated for its metallurgical and mechanical properties. Results reveal there is a uniform particles distribution in the given alloy matrix and existing strong bonding between matrix and the reinforcement. Grain refinement in the alloy matrix is observed by inducing nano size slag particulates. Further prepared metal matrix nano composites show lower grain size values than base alloy. Nano composites show better mechanical properties than base alloy. This is further enhanced by ageing treatments. Interestingly, nano composite exhibits increasing strength with good ductility; same is confirmed with fracture studies.

Keywords: AA7075 alloy, Industrial solid waste, Nano materials, MMNCs

Processing of FCC Titanium through Hot Rolling

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A micro-scale partial transformation of HCP structured titanium alloys to the FCC has been reported by several researchers. FCC structure is expected to enhance mechanical properties of otherwise titanium with HCP/BCC structure. This was elucidated by limited modeling exercise due to the absence of bulk FCC Ti. The present work is concentrated around the Beta transus zone, which is established by means of dilatometry for the titanium alloy (Ti-6Al-4V). The forming process chosen for this work is Hot Rolling for obvious advantage of bulk material processing. The formation of stable FCC titanium through hot rolling process is confirmed by the SAD analysis of TEM. FCC structure is found in the colonies of twins formed due to the high rate of cooling after hot deformation. The result of this study clearly demonstrates that through the process of hot deformation followed by the high rate of cooling can produces the metastable FCC structure within the Ti-6AL-4V having HCP structure.

Keywords: Titanium, FCC, Hot rolling, TEM, Twins.

Studies on Production of Ferro-moly Alloy from Spent Catalyst Residues

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Catalyst are used to refine the crude oil to produce gasoline, low sulfur diesel, petrol & other valuable products in the petroleum industries. These catalysts are made by doping heavy metals (molybdenum, nickel, cobalt) in porous ceramic substrate. While in use these catalysts are loaded with the toxic heavy metal oxides and sulphide, which make them further unusable, hence discarded as spent catalyst. These spent catalysts are generated worldwide in the range 1.5 -1.8 lakh tons/annum and have valuable metallic content viz Mo, Ni, Co which can be extracted economically. These spent catalysts create an environment threat because of their leachability and pyrophoricity, hence can't be dispose of as a landfill material. A considerable effort has been made, which includes immobilization of spent catalyst in an inert material and use of metallurgical extraction techniques to recover the Mo, Ni and Co metals/compounds from it.

Spent catalyst have metals in oxide form, thus, carbothermic reduction route could be a possibility to obtain metals in alloy form while rejecting impurities in slag. The development of carbothermic reduction process route to treat spent catalyst (containing 10-15% Mo, 2-4 % Ni, 1-2% Co, 30-35 % Al) in presence of iron bearing material and fluxing material to collect the reduced metals and alumina rich slag. Initial thermodynamic calculations for recovery of metallic value from spent catalyst were studied using software FactSage 6.4. Based on the outcome, actual experiments were done using spent catalyst residue in a 50 kVA electric arc furnace at 1500 – 1600 ^{o}C with reductant and fluxes. The produced Fe-Mo alloy will be used in special alloy steel manufacturing and the alumina rich slag will be used as a raw/blending material for the cement industry. Optimum Alloy composition [55-60% Fe, 20-25% Mo, 6-8% Ni, 1-2% Co, <1% C, <0.1% P and <0.05 S] and slag having [50-55% CaO, 40-45% Al_2O_3, 1-2% Fe_2O_3, 0.5 -1% P_2O_5, 0.3-0.7% S] was produced at 1500-1600 ^{o}C.

Reclamation of Lithium, Cobalt and Manganese from Spent Toys Batteries

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The rechargeable batteries are widely used in the various electronic devices i.e. mobile phone, laptops, toys vehicle etc. The lifespan of toys' vehicle batteries is comparatively very short. Therefore, enormous amount of discarded toys' batteries is generated. Illegal dumping may cause serious environmental threat as well as loss of valuables metals. In a view of the above, the studied have been made to recycle the discarded toys batteries. Initially, discarded batteries were beneficiated to get the black cathodic materials. The obtained black powder mainly contains lithium, cobalt, manganese and nickel, which was used for the recovery of metals by advanced hydrometallurgical techniques. To optimize the parameters, experiments were carried out varying the process conditions such as acid concentration, reaction time, reductant concentration, pulp density etc. for the dissolution of Li, Co, Ni and Mn from LIBs. Results showed that 99.6% Mn, 99.2 % Li and 98.8% Co were leached with 1 mol/l H_2SO_4 in presence of 2.5% H_2O_2 (v/v) at 30 °C in 10 min, at pulp density 75 g/l.

Further, solvent extraction and precipitation method were used to recover the nickel, cobalt, manganese, lithium from leach liquor of black powder. It was found that complete extraction of nickel (~99%) occurred with LIX 84 at eq. pH ~ 5, while Li, Co and Mn remained in the solution. Thereafter, 80.2% Co was precipitated in a pH range of 6.5 to 7.9; whereas (99.1%) manganese precipitation occurred in range of pH 10 to 11.5 leaving lithium in the solution. The purified solution can be used for the recovery of metals in form of their oxide/hydroxide or in metallic form by precipitation/electrolysis.

Keywords: Toys batteries, Beneficiation, Leaching, Solvent extraction, Precipitation, Metals oxide/hydroxide

Removal of Barium Sulphate Mould Wash from Copper Anode to Improve Electrorefining Operations

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Refining of blister copper consists of fire refining followed by casting of anodes to improve the purity from 98.2 to 99.5 %. Copper cast anodes should possess physical and chemical quality to meet the requirements for electro refining. During casting of anode, barium sulphate suspension is used as a mould coating which adheres to the surface of the anode during solidification. During subsequent electro refining, adhered mould wash settles at the bottom of the electrolytic cell along with anode slimes. The quality of anode slimes deteriorates along with increase in volume, which further reduces the precious metals concentration. Also, barite mould wash is the major contributors for the increased volume of slag in precious metal refinery. Therefore, it is essential to substantially minimize the carryover of barium sulphate into the electro refinery.
Estimation of mould wash distribution in different streams was carried out. The study reveals that 80 % of barite used during anode casting is carried over to refinery as adherent to the anode surface. Abrasive shot blasting and hydrojet techniques were investigated to reduce the adhered barite on the anode surface. The details of the pilot scale studies conducted by using both the techniques are presented. It was also observed that the short-circuiting due to nodulation during electro refining is reduced by 50 %.

Keywords: Anode casting, Barite, Slimes, Electro refining, Abrasive shot blasting, Hydrojet

Development of Feasible Process for the Recovery of Precious Metals from E-waste

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The launch of smart electronic gadgets with new and advanced features has reduced the life span

of various electronic devices (computers, mobiles, telecom and medical equipments, connectors, signal devices, etc.) that has led to the generation of huge amount of obsolete electronic devices. All these electronic devices contain a printed circuit board (PCBs), which is made up of various metals/materials. Due to the unique properties such as corrosive resistance and excellent thermal and electrical conductivity, precious metals *viz.* silver, gold, palladium and platinum are widely being used in the manufacturing of electronic devices. In the international market, price of precious metals is increasing rapidly due to increase in their demand. The electrical and electronic manufacturing industries are the main consumer of precious metals (Ag, Au, Pd and Pt).
In view of the limited natural resources of precious metals, stringent environmental regulations and generation of huge amount of electronic waste (e-waste) compels to develop feasible technology to recover precious metals for circular economy and sustainable development. Based on the above motivation the present paper reports a review on the indigenous feasible technologies developed at CSIR-NML, Jamshedpur to recover precious metals (Ag, Au, Pd and Pt) from e-waste using pre-treatment followed by hydrometallurgical techniques. The developed process flow-sheets are feasible and will be helpful to generate a new market for precious metals from secondary resources.

Keywords: Precious metals, E-waste, Recycling, Hydrometallurgy

Possibility of Recovery and Reuse of Filter Aid in Bayer Plant

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In alumina refineries, bauxite is digested in a caustic solution under elevated temperature and pressure to extract the alumina from bauxite. In this process large amount of waste, called bauxite residue (red mud) are generated.
The separation of the mud from the concentrated liquor is carried out in the decanter using flocculants. The decanted liquor (or pregnant liquor) having some of the finest suspended mud particles overflows from the decanters. The decanted liquor then further clarified through filtration using pressure filters. This is called "security' or "polishing" filtration and it is critical in ensuring that the pregnant liquor is free from suspended mud particles that would otherwise result in contamination of the product alumina.
During the security filtration of the pregnant liquor, cake is formed consisting of bauxite residue and filter aid. The most common filter aid used in alumina industry is the tricalcium aluminate hexahydrate (TCA). TCA is formed by the reaction of lime with the Bayer process liquor, which

has the ideal formula of $Ca_3Al_2(OH)_{12}$. Here, the filtration efficiency is directly related to the quantity and quality of filter aid used. Once blinding of the filter cake occurs, the filter aid must be replaced with fresh aid. This filter cake is discarded and becomes a reject of the alumina industry.

This work is related to find out the possibility of recovering TCA and reuse of recovered TCA (RTCA). Studies also conducted to find out the effect of RTCA on cake resistance and filtration. The study reveals that the recovery and reuse of the filter aid is very much feasible also beneficial to the process. Thus, TCA recovery would minimise the generation of waste and reduce the consumption of raw materials, such as lime, which would reduce the environmental impacts due to waste generation. Economics shows that it would be possible to save ~ Rs 60/t of alumina through TCA recovery and reuse.

Chemical Pre-treatment of Integrated Circuits (ICs) of Discarded Mobile Phone to get High grade PMs Concentrate

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Due to some special characteristics, the demand of precious metals (PMs) has increased in the manufacturing of electronic goods. Rapid modernization in feature of electrical and electronic equipments (EEEs) has played vital role in the generation of waste EEEs (WEEEs) containing PMs. The significant amount of PMs present in WEEEs compelled researchers to develop its recuperation processes in view of economic stability as well as resource conservation. Integrated circuits (ICs) of discarded mobile phones, an important source of PMs were used for this study. ICs were separated from PCBs using thermal treatment, further crushed and milled to make it powder. Fine powder will have more surface area, which will be helpful in easy dissolution process. After the selection of suitable leachant, various process parameters i.e. leachant concentration, pulp density and time and temperature on leaching of metals were optimized to recover precious metal Silver (Ag) along with other metals as valuable products. The enriched metallic concentrate containing Gold (Au), Palladium (Pd) and Platinum (Pt) in the residual part was obtained. Based on the experimental studies the leaching percentage of Ag, Cu, Ni and Fe were found 99.71%, 99.61%, 99.99%, 99.6%, respectively with 4 M HNO_3 using 50 g/l of pulp density in 30 minutes mixing time at 90 ^oC, and the concentration of Au, Pd and Pt in residual part was found to be enriched from 0.60 – 0.76%, 0.01 – 0.017%, 0.0004 – 0.0005% respectively. The result of studies will be useful for the researchers, students and industrialists working for the e-waste recycling.

Keywords: Precious Metal, Leaching, Enrichment, Metallic Concentrate

Electrometallurgical Route of Extraction of Precious Metals from E-waste

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Rapid industrialization along with recent technological advances and new evolving consumer pattern trends has subsequently led to net decrease in useful life of electronic equipment. This has resulted into generation of a huge amount of stockpiled electronic waste. Earlier used disposal techniques such as incineration, landfilling or exporting overseas in no longer permitted owing to its adverse environmental impact and strict global legislations. The presence of various precious metals (gold, platinum, silver, palladium etc.) in the E-waste makes recycling an attractive and economically viable option. Hence the recycling of the metals present may be a better alternative for sustainable development to meet the needs of present generation in the most economic and viable manner. But the exorbitant cost of metal extraction from the waste requires a deep insight into extraction techniques used so far. Various routes of metal extraction such as hydrometallurgy, pyrometallurgy, thermal depolymerization etc. are accountable but have their own drawbacks such as generation of acidic effluent and release of toxic gases. Hence a brief review of the current trends in development of low-cost techniques using electrometallurgy for the extraction of metals from e-waste have been provided in the present article.

Keywords: Electrometallurgy, E- waste

Recycling of Scrap Nd-Fe-B Permanent Magnets to Reclaim REMs Salt

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Permanent magnets are widely used in the electronic devices due to its promising and constant electromagnetic properties. Huge quantity of waste magnets is generated due to the end-of-life of devices/magnets. The recycling of Nd-Fe-B magnet is essential to comply with environmental regulations and to help to reduce the demand and supply gap of REMs. Present paper reports a feasible process consists of demagnetisation-pre-treatment roasting and water leaching to reclaim rare earth metals (REMs). Initially the waste magnets were demagnetised by heat treatment up to the temperature 300 °C for 3 h. The brittle and demagnetised magnets were crushed and sized to less than 100 mesh. The fine crushed magnets containing 29.45% of Nd, 2.5% of Dy, 1.25% of Pr, 59.5% of Fe, 3.05% of Co and 4.05% of Ni were put for roasting with 20% Calcium hydroxide at 750 °C for 1 hr to make the rare earth metals water soluble. The 99% recovery of Nd, Dy and Pr were obtained in two stage water leaching by maintaining 100 g/l pulp density at 75 °C for 1 h. Excess amount of Fe remained were used to prepare red oxide pigments. The effluent generated was recycled to the closed loop process. The process is feasible and has potential to be used for commercial exploitation.

Keywords: Nd-Fe-B magnets, Hydrometallurgy, Leaching, Roasting, REEs

Selective Extraction of Lithium from Cathodic Materials of Spent Lithium-ion Batteries

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LIBs are widely used in the electronic devises due to its high energy storage capacity than the other rechargeable batteries. It led to increase the consumption of LIBs, but significant number of LIBs became obsolete after reaching its end of life. Therefore, present work focused on the selective recovery of lithium from the cathodic materials of spent lithium-ion batteries by roasting and leaching process. To optimize the conditions for roasting of cathodic materials of LIBs, studies were carried out varying process parameters such as roasting time, temperature, mass ratio of urea etc. Result shows that complete conversion of insoluble phase of Li contained in cathodic materials were oxidized to water soluble species of Li at elevated temperature in maximum contact time while maintain the mass ratio of cathodic materials to urea double. Further, roasted cathodic material was leached in distilled water to selectively leach the lithium. 97.9% Li was found to be

leached at 75 °C in 2 h, while Co, Mn and Ni remained in the leached residue at pulp density 100 g/l. Further, lithium could be recovered as lithium carbonate by evaporating the solution.

Keywords: LIBs, Cathodic materials, Roasting, Leaching, Lithium

POSTER PRESENTATIONS

Effect of ODS on the Transverse Rupture Strength and Compressive Strength of W-Ni-Cu Heavy Alloys

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Tungsten heavy alloys are dual phase composite materials that contain 80-97 wt% BCC tungsten particles embedded in the FCC ductile matrix. The matrix contains transition elements such as Ni, Cu, Fe, Co, etc. The high strength (1000-1700 MPa), high density (16-18 g/cm^3), ductility, and corrosion resistance make the best candidate for the field of kinetic energy penetrator, counterbalance parts, and radiation shields. The most used tungsten heavy alloy is W-Ni-Fe and W-Ni-Cu. Depending upon the application the W-Ni-Fe, W-Ni-Cu, and W-Ni-Co ternary alloys are used. The W-Ni-Fe has excellent mechanical properties as compared to W-Ni-Cu heavy alloys. The powder metallurgy is the best route to fabricate the tungsten heavy alloys at the range of temperature 1300 °C to 1500 °C. Tungsten-heavy alloys are mostly fabricated by the liquid phase sintering. The key parameters which decide the mechanical properties are heating rate, binder compositions, sintering time, sintering temperature, and sintering environment. From the metallurgical point of view, strengthening mechanisms is one of the methods to improve the mechanical properties of tungsten-heavy alloys. These strengthening mechanisms are reported as plastic deformation, dispersion strengthening, grain refinement, etc.

The current study is carried out on W-Ni-Cu heavy alloys. The @W-Ni-Cu-x(Y_2O_3) alloys powders were mixed in a Turbula Shaker mixer for 10 hr. The pre-mixed powders were compacted on a Hydraulic press. The green compacted samples were sintered in a Tubular furnace at 1400 °C temperature. The sintering was done in a hydrogen atmosphere for 1 hour holding time. It is expected that the liquid phase sintering was achieved. This study aims to effect densification behavior by the addition of dispersion element Y_2O_3. The mechanical properties were observed especially Transverse rupture strength and Compression strength. The Vickers hardness was employed to calculate the bulk hardness of ODS heavy alloys. The fractography signature was observed and found the fracture nucleation sites.

The Role of Microstructure Inhomogeneity on the Fracture Toughness of Ti-6Al-4V Alloy

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The processing route of $\alpha + \beta$ titanium alloy mainly consists of homogenization, deformation, and annealing steps. The as-cast ingot, homogenized above the β-transition temperature and on cooling, leads to α/β lamellar microstructure development. In the deformation steps, the lamellar morphology needs to be broken down to develop globular structures, which on subsequent mill annealing produces the equiaxed microstructure. The mill annealed microstructure is easy to process and generally preferred for forgings. It is observed that the titanium forgings have a localized texture, commonly known as macrozone. These macrozone consisting of crystal structures of similar c-axis, mostly develop during the deformation step of ingot processing, leading to variation in fracture toughness. Recently, it is reported that these macrozones can be suppressed by the annealing process.
Miniature fracture toughness samples were designed and sectioned out from the previously tested CT-specimen of valid thickness as per ASTM E399, from the forged part. Further, one sample was tested for $K_{IC,}$ and the remaining were annealed to develop the homogenous microstructure intending to suppress the macrozone. Subsequently, fracture toughness tests were performed on the annealed miniature samples to understand the role of microstructure/local texture variation on the K_{IC}. The microstructure and texture were characterized by electron backscattered diffraction (EBSD) and X-ray diffraction (XRD) techniques to establish the macrozone suppression and mechanical properties.

Keywords: Ti-6Al-4V, Macrozone, Fracture toughness-K_{IC}, Annealing

Role of Microstructural Anisotropy on the Fatigue Crack Growth in Inconel 718

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The dependence of the fatigue crack growth behaviour of hot forged Inconel 718 on the microstructural anisotropy of material was investigated. It goes without saying that these alloys produced by forging have a significant anisotropy of the mechanical properties, in particular the fatigue characteristics. The present research deals with studying the anisotropic effects, with particular attention being paid to the fatigue crack growth behaviour in the low-cycle fatigue range. For this purpose, possible relationships between a large number of tested microstructural parameters and the results from low-cycle fatigue (LCF) was corelated.
In order to identify the prevailing damage mechanisms, failure analyses were carried out on a few number of samples that have been sectioned in different orientations in relation to the forging direction. Optical and scanning electron microscopy techniques was used for detailed analysis. With the help of optical microscopy and energy dispersive X-ray analysis (EDX) performed at the crack initiation points, possible accumulations of alloying elements and secondary phases or inclusions if any could be detected. With the help of EBSD, grain boundary slip mechanisms, crystallographic textures, and strain heterogeneity could be investigated and related to possible crack formation mechanisms.

Effect of Keyhole Gas Tungsten Arc Welding of the Ni-base Superalloys HY282 and IN740H

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The γ'-strengthened Ni-base superalloys Haynes 282 (HY282) and Inconel 740H (IN740H) are

developed for high-temperature structural applications in aero- and land-based gas turbine engines. Since welding is a crucial process during the manufacturing and repair of turbine engine parts, it is essential to study its effect on the microstructure and properties of these alloys. An advanced version of the gas tungsten arc welding (GTAW) method has emerged in the recent decades which enables deeper penetration welding at high speeds and thus leads to higher productivity. Termed as keyhole GTAW, this technique has been shown to be suitable for many steels, titanium and some nickel alloys. However, the relatively higher heat input employed in keyhole GTAW, may affect the microstructure of Ni-base superalloys adversely. In this study, we aim to understand the effect of this high-current keyhole mode GTAW process on the microstructure and properties of HY282 and IN740H. Through a systematic variation of welding parameters, we arrive at a critical heat input value for achieving full penetration in 3 mm thick bead-on-plate welds. Solidification cracking is not observed in any of the welds. Microstructural characterization reveals a solidification structure consisting of γ dendrites and an interdendritic network. Although the heat affected zone (HAZ) is not easily distinguishable from the base metal (BM) visually, microhardness profiles across the weld reveals a drop in hardness in HAZ and thus clearly identifies the HAZ-BM boundary. We carry out thermodynamic simulations using Thermo-Calc to understand phase formation in the fusion zone and HAZ, and correlate the microstructure with the mechanical properties of the welds.

Effect of Annealing Process on Microstructure and Mechanical Properties of Zr-4 alloy Processed by Rotary Swaging

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Zr-4 alloy are used as a cladding material in nuclear reactors due to its high neutron absorption cross section, excellent tensile properties, fracture strength, and corrosion resistance. A rotary swaging is a process that reduces the cross-sectional area of solid rods by repeated radial blows with one or more pair of opposed dies. Microstructural evolution and mechanical properties of Zr-4 alloy with different annealing parameters (annealing temperature and time) were investigated by optical microscope, electron backscattered diffraction (EBSD), transmission electron microscopy (TEM) and microhardness testing. The grain size, misorientation distribution and texture of the annealed Zr-4 alloy is characterized by using EBSD. The dislocation mobility, precipitates, and formation of annealing twins were characterized by TEM. The optimum annealing conditions for swaged Zr-4 alloy is reported in present work.

Keywords: Swaging, Zr-4, Annealing, EBSD, TEM

Corrosion Behaviour of Al-Si alloy made in Sand and Slag Moulds

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In the present research, the effect of moulding materials on microstructure and corrosion behaviour of Al - 7% Si (A356) alloy was investigated. Three types of mould materials are used in the current investigation. These are Silica sand, Granulated Blast Furnace (GBF) slag and Ferro Chrome (Fe-Cr) slag. The CO_2 moulding process has been adopted. They were pitting behaviour of cast samples in 3.5% NaCl solution in as-cast and T6 conditions. The corrosion studies were carried out for one month using the weight-loss method. Immersing the peak aged specimens in 0.1M acid chloride, 0.1M acid sulphate, 0.1M acid nitrate, and 3.5% neutral chloride medium at room temperature for 7days and continuously monitoring the weight loss for a month. The result obtained shows that in pitting corrosion, Fe-Cr slag mould samples show superior corrosion resistance in as-cast and T6 conditions compared to sand and GBF slag moulds. The weight loss of the specimens determines the immersion test, the corrosion rate. It is evaluated using the origin pro 8.5 software by plotting the corrosion rate against time in hours. Corrosion occurs at a slower rate in neutral chloride medium than in other mediums, according to studies. Compared to weight loss in different mediums, the Fe-Cr slag mould shows a lower weight loss and corrosion rate than the other two cast products. This might be due to Fe-Cr slag mould castings exhibited a lower aspect ratio of eutectic silicon, fine grain size, and lower porosity values resulting in more corrosion resistance.

Keywords: A356 alloy, Casting, Slags, Corrosion studies

Evaluating the Corrosion Response of Ultrasonically Shot-Peened Squeeze-Cast AZ91 Alloy Reinforced with Graphene Nanoparticles

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AZ91 magnesium alloy is one of the prevalently utilized Mg-Al alloy, however, it does not exhibit good corrosion resistance, because of the presence of higher content of the $Mg_{17}Al_{12}$ phase. During the past many decades, AZ91 alloy has been modified through alloying addition improving its mechanical as well as corrosion properties. However, the corrosion response of these modified alloys is limited owing to the formation of cathodic secondary precipitates. Thus, AZ91 alloy-based nanocomposites exhibiting greater elastic modulus, augmented strength, superior creep, and resistance to wear, making them a potential solution to the above-mentioned challenges. However, the integration of nano-sized particles into the AZ91 alloy matrix can significantly influence its microstructure which can play a major role in governing its corrosion response. Besides, the shot peening (SP) process is a plastic deformation technique, where compressive stresses along with strain hardening are induced in the upper layer of the material that considerably affects the surface properties and corrosion property is one of them. Accordingly, the current work evaluates the effect of shot peening (SP) on the corrosion behavior of the AZ91 alloy reinforced with graphene nanoparticles (GNPs), fabricated by the squeeze-casting technique. The corrosion response of AZ91-xGNPs (x = 0.5, 1.0, 2.0 wt.%) nanocomposites with and without shot peening was analysed employing immersion and electrochemical methods in 0.1M NaCl solution. The results displayed that the corrosion rate of the shot-peened nanocomposites is significantly lower than the non-shot peened specimens, suggesting that the shot peening method is an effective way to reduce the corrosion rate.

Keywords: AZ91 magnesium alloy, Nanocomposites, Squeeze casting, Corrosion behaviour, Shot peening

Effect of Si Addition on Phase Evolution and Microstructure in Y_2O_3 Dispersed Tungsten (W) and W-Based Alloys Synthesized via Mechanical Alloying and Consecutive Conventional Sintering

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Oxide dispersion strengthened (ODS) tungsten (W) alloys are progressively used for critical engineering applications like high temperature, fast wall in nuclear reactor and kinetic energy penetrator. Besides their achievements related to high strength and resistance to radiation, ODS W alloys have downsides such as formation of highly volatile WO_3 compound at high temperature due to oxidation. To suppress oxidation of W and W based alloys, various self-passivating ODS W alloys are developed by adding silicon which forms a protective oxide layer on the tungsten alloy surface when they come in contact with oxygen and prevents further oxidation. The present research reports the fabrication of nano yttria (0.3 wt. %) dispersed pure W, W-10Ni, W-10Ni-3Co, W-1Si, W-10Ni-1Si, and W-10Ni-3Co-1Si alloys by mechanical alloying (MA) of W, Ni, Co, Y_2O_3, and Si powders for 10 h and consecutive consolidation via conventional sintering under H_2 gas atmosphere at 1500 °C for 2 h. It has been found that the addition of 1 wt. % Si causes a faster reduction in particle size and results in finer and uniform particles. The X-Ray diffraction and transmission electron microscopy analysis reveal the formation of nano-scale WSi_2 intermetallic compound in the W-1Si-0.3Y_2O_3 alloy and it is observed that the Ni and Co addition prevents the formation of the intermetallic compound in the W-Si alloy systems during milling. However, the appearance of SiO_2 oxide phase in W-10Ni-1Si-0.3Y_2O_3 and W-10Ni-3Co-1Si-0.3Y_2O_3 alloys is observed after sintering. The values of crystallite size, relative density, and hardness values are measured for investigated alloys. Sintered densities of 95% and 96% are observed in the case of W-10Ni-1Si-0.3Y_2O_3 and W-10Ni-3Co-1Si-0.3Y_2O_3 alloys respectively. The highest hardness value of 5.4 GPa is achieved in W-1Si-0.3Y_2O_3 alloy with a sintering density of 82.3%. The effect of Ni and Co along with Si in ODS tungsten alloys has been studied and the phase evolution, microstructure, density and hardness of the fabricated alloys have also been investigated.

Preparation and Characterization of in-situ based Al-$MgAl_2O_4$ Composite Prepared by Stir Casting Route Assisted with Ultrasonic Treatment

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Al-$MgAl_2O_4$ composites are prepared via stir casting route and subsequently the melt has been subjected to ultrasonic vibrations. The mechanism of the composite formation viz the displacement reactions and the synthesis of well dispersed $MgAl_2O_4$ particles in the matrix and the effect of UT has been discussed. Three different holding times before casting; 0, 15 and 30 minutes are employed in the preparation of the composites which has resulted in the variation of some properties of the composite like percentage of second phase particles, hardness, etc. Further, from the SEM and EDS analysis, the presence of second phase particle i.e., $MgAl_2O_4$ has been confirmed. XRD analysis of the Al-$MgAl_2O_4$ composites with different holding times of 15 and 30 minutes is carried out to support the above results. The empirical relationship between hardness and wear rate, hardness and tensile strength reveals that with an increase in hardness, the wear rate decreases and tensile strength increases.

Pore Morphology and Cell Wall Mechanical Properties of Aluminium Foam Developed by Stir Casting Route

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In the present work, aluminium foam has been developed using calcium carbonate ($CaCO_3$) foaming agent by stir casting route. A detailed investigation on the effect of amount of foaming agent on the microstructure, density, porosity, hardness, and cell wall mechanical properties has been undertaken. The micro-computer tomography (μ-CT) technique has been used to investigate the pore morphology, such as porosity, shape, size, and sphericity of developed foam. The cell wall mechanical properties of developed foam have been investigated through Nano Indentation (NI) technique. The results show that, as the percentage of calcium carbonate increases, the relative

density of the foam decreases from 0.31 to 0.23 and microhardness of the foam decreases from 56 HV to 47 HV. The Nanoindentation results also show that the cell wall mechanical properties such as nano hardness decreases from 994.38 to 735.67 MPa and Young's modulus of the foam decreases from 87.78 to 66.67 GPa decreases with increasing the percentage of calcium carbonate foaming agent.

Keywords: Aluminium foam, calcium carbonate, cell wall strength, nanoindentation

Corrosion Behaviour of Friction Stir Welded AA6082 with AA7075 Similar & Dissimilar Joint

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Corrosion behavior of friction stir welded AA6082 & AA7075 materials joint of similar and dissimilar aluminum alloy was investigated by immersion tests in sodium chloride and nitric acid solution. The optimum parameters are feed rate 80mm/min, tool rotation speed 900Rpm, tilt angle 2^{o}. Similar and dissimilar joints of 100 x 100 x 6 mm^3 plate were welded with conical tapered tool pin profile. The tensile strength, microstructure and micro hardness of welded joint were investigated. Corrosion studies includes immersion test by weight loss method and electrochemical method. It was showed that the AA6082-7075 joint has good corrosion resistant in NaCl solution.

Compressive Behaviour of Aluminium Foams Stabilized by Oxide Particles via Melt Route

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This paper reports the compressive performance of closed-cell Al foams produced from pure aluminum (Al) through melt route. The foams were prepared at 680 °C by admixing a mixture of 1.5 wt.% titanium hydride, as a blowing agent and Al powder into the Al melt. Macrostructural and microstructural characterization were performed by employing optical imaging, and scanning electron microscopy. Elemental mapping technique was used to characterize the oxides and phases present in the cell structure. Uniaxial – static compression tests were conducted to analyze the compressive performance of the Al foams. The foams were stabilized by the oxides inherently present in Al powder and by the oxide particles entrained in the melt due to oxidation. The compression test results showed lower compressive strength and energy absorption capability as compared to other foams. In addition, foams exhibited inferior energy absorption efficiency, as a result of strain hardening observed in the stress-strain response of foams. The mechanical properties of the foams are mainly affected by the increased foam density due to the presence of clustered oxides and thick cell walls. However, the procedure used to prepare these foams are cost effective and utilize simple processing steps. Both the physical and mechanical properties of such foams are compared with foams prepared by traditional routes.

Keywords: Aluminum foams, Melt route, Mechanical properties, Oxides, Aluminum powder

Production of Super Specialty 6000 Series Aluminium Billet

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Aluminium is the most important non-ferrous metal next to copper. It is recognized as the “Energy Efficient metal” for its intrinsic properties. It exhibits excellent corrosion resistance, electrical / thermal conductivity. The properties of aluminium vary with its purity. An addition of other alloying elements such as magnesium, silicon, copper, chromium, manganese, strontium, lithium, zinc etc. improves its other properties such as UTS, yield strength, maximum load taking capacity, impact strength, micro hardness, Young’s modulus, elongation at UTS, etc. The various mechanical properties were further improved by proper homogenization at elevated temperature vis-à-vis proper cooling. To meet the 1uality requirements in architecture, house hold items, automobiles, small machine components, rail wagons, yacht construction, commercial aircraft structures such as wings, fuselages, wing stringers, air ducts, helicopter rotor components, armaments (tanks), ultra high vacuum (UHV) chambers (in power industries), bicycle f rames and its other components etc. a “Superspecialty 6000 Series Alloy Grade Billet” was produced in the Smelter Plant, NALCO in 2019. It is a market driven grade, produced to capture more customers and maintain edge over competitors. Addition of strontium leads to the breakdown of the β–Al_5FeSi needles/platelets into smaller fragments without change in the intermetallic type. The size of Mg_2Si was less than 1 μm which indicates that the extrusion industries did not face any “Pick

Up" problem.

Keywords: Energy Efficient, Homogenisation, Elevated Temperature, Proper Cooling, Intermetallic type, Pick Up

Premature Failure of Fork-End of Main Rotor Control Rod of a Helicopter during Fatigue Test

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One of the main rotor control rods viz. the collective booster rod of a military helicopter was subjected to fatigue (functional) test. Fatigue testing was carried out at load level of ±10 kN. The fatigue specimen had completed about 3.5 million cycles against the requirement of 10 million cycles, when crack was detected in fork-end of the rod. Crack had extended from bore to edge of the fork-end and also through and through its wall thickness. In actual assembly, bush is press-fitted into bore of the fork-end. The fork-end was made of Ti-6Al-4V alloy and was in solutionized and aged condition.

Laboratory investigation was carried out on the failed fork-end to establish the reason for failure. Material of construction (MoC) of the fork-end met all the specified requirements. Scanning Electron Microscopy of crack (fracture) surface showed presence of fatigue striations. It was inferred that the fork-end had failed by fatigue. Fatigue crack had originated at one of the edges of the bore of the fork-end.

It was observed that the bush press-fitted into bore of the fork-end had made non-uniform (preferential) contact mark around the bore periphery. This suggested improper press-fitting of the bush. This had caused minute relative motion between the contact surfaces of fork-end and bush resulting in fretting. Improper press-fitting of the bush (assembly error) was identified as the reason for premature failure of the fork-end. The systematic analysis conducted to arrive at the cause of failure and the remedial measures suggested are described in the present paper.

Keywords: Helicopter, main rotor control rod, fork-end, Scanning Electron Microscopy, fatigue, striations, fretting, assembly error

Study on Weld Bead Morphology of Electron Beam Welded Ti-6Al-4V at Different Welding Speeds

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Titanium alloys have gained a good reputation in aerospace applications due to their low strength-to-weight ratio, corrosion resistance and outstanding mechanical performance. Welding of these alloys is difficult as they are highly reactive. Recently electron beam welding (EBW) process has been developed to eliminate the difficulties associated with the Ti welding process and prepare sound welds. In the present study, the influence of welding speed on microstructure and mechanical properties of electron beam welded Ti-6Al-4V has been studied. Optical microscopy has revealed three different zones viz., Fusion Zone (FZ), Heat Affected Zone (HAZ) and Base Metal (BM). With the increase in welding speed, heat input was reduced, and it further reduced the FZ size. The microstructure of the base metal comprised of slightly elongated α phase and transformed β phase, while the microstructure of the FZ consisted of acicular microstructure. The microstructure of the HAZ consisted of two distinct regions like fine and coarse grain zone regions. This variation in microstructure from FZ to BM though HAZ will lead to variation in the hardness across the weldment in the transverse direction.

Keywords: Ti-6Al-4V, Welding speed, Hardness testing, UTM

Effect of Ageing on Microstructure, Mechanical and Pitting Corrosion Behaviour of AA1441 Al-Li Alloy Friction Stir Welds

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Al-Li alloys are attractive material for military and aerospace applications because their properties are superior to those of conventional Al alloys. Despite their low density, high strength along with

high elastic modulus, welding can have significant influence on mechanical and corrosion resistance due to microstructural changes arising from the welding thermal cycles. Fusion welding of Al-Li alloys results in weldability issues like solidification cracking, porosity, liquation cracking, low joint efficiency and segregation which were arises due to microstructural changes. However above problems can be avoided by using solid-state welding like friction stir welding. AA1441 Al-Li alloy is a precipitation hard enable alloy, Al_3Li(δ') metastable phase from supersaturated Al-Li solid solution leads to appreciable increase in strength. In view of the above present work is aimed at studying the effect of post weld single ageing and double ageing heat treatments (solutionizing at 530 ^{0}C for 1 hour followed by single ageing at 150 ^{0}C for 16 hours and double ageing at 170 ^{0}C for 24 hours) on AA1441 Al-Li alloy friction stir welds. Present investigation was carried out on microstructural, mechanical and corrosion behaviour. Micro-structural study was conducted by using Leica optical microscope and micro-Vickers hardness tester was used to study the hardness properties. Potentio-dynamic polarization studies were conducted in aqueous solution of 3.5% NaCl aerated environment by using basic GillAC electrochemical system. Present study was planned to compare the mechanical and pitting corrosion behavior of as welded and post weld heat treated conditions of AA1441 Al-Li alloy FS welds. It has been observed that, re-precipitation and re-distribution of dissolved strengthening precipitates (during FSW) due to double ageing may the main reason for improvement in mechanical and pitting corrosion behaviour of AA1441 Al-Li alloy.

Keywords*:* Al-Li, AA1441, PWHT, FSW

Mechanical Properties of Post Weld Heat Treated Grade 5 Titanium Friction Welds

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Grade 5 Titanium alloy is widely used in aerospace, biomedical applications, joining this alloy by conventional fusion welding techniques leading defects such as solidification cracking, wide Heat Affect Zone, porosity etc. In order to avoid such problems, solid-state welding techniques emerged, especially friction welding is used for joining critical components. In this investigation Grade 5 Titanium alloy in mill annealed condition is friction welded at rotational speed, 1500 rpm and 5 kN upset force, post weld heat treatments in α+β and β condition was applied, followed by furnace cooling and air cooling, its effects on mechanical properties such as hardness and tensile properties have been studied.

Keywords: Grade 5 Titanium alloy, Friction Welding, α+β condition, β condition, Hardness, Tensile Properties.

Energy, Environment and Waste Utilization

Enhanced Atomic Ordering and Nanostructuring Boost the Thermoelectric Performance to an Ultra-high Value

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About 2/3rd of all utilized energy is being lost as heat. Thermoelectric materials can convert waste heat to electrical energy, and it will have significant role in future energy management. High thermoelectric performance is generally achieved either by electronic structure modulations or through phonon scattering enhancements, which often counteract each other. A leap in performance requires innovative strategies that simultaneously optimize electronic and phonon transports. We demonstrate high thermoelectric performance with a near room-temperature figure of merit, zT ~1.5 and a maximum zT ~2.6 at 573 K by optimizing atomic disorder in Cd doped polycrystalline $AgSbTe_2$[1]. Cadmium doping in $AgSbTe_2$ enhances cationic ordering, which simultaneously improves electronic properties by tuning disorder-induced localization of electronic states and reduces lattice thermal conductivity via spontaneous formation of nanoscale (~2-4 nm) superstructures and coupling of soft vibrations localized within ~1 nm around Cd sites with local strain modulation. The strategy is applicable to most of the other thermoelectric materials which exhibit inherent atomic disorder.

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Advanced Technology for Wastewater Sludge Treatment: Thermal Hydrolysis Process (THP)

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Wastewater generated from cities, homes, industries, and commercial centres are treated in wastewater treatment plants (WWTPs). WWTPs give two products – (i) treated or purified wastewater which can be discharged or recycled and reused and (ii) sludge. Sludge is a mixture of solid particles and wastewater which contains carbon and other nutrients. As more and more WWTPs are being built, disposal of sludge is becoming a challenge. Sludge can be treated in anaerobic digesters to: (i) reduce the volume of solids to be disposed, (ii) stabilize the sludge and (iii) produce biogas (mainly a mixture methane and carbon dioxide). The biogas produced can be cleaned and used in combined heat and power (CHP) equipment to produce heat and electricity or used as a fuel for running buses, cars etc. However, the digested sludge so produced still contains pathogens (disease causing bacteria) and requires strict disposal monitoring and record keeping. Treated sludge is called biosolids.

Thermal Hydrolysis Process (THP) is an advanced anaerobic process which is placed ahead of the anaerobic digesters as a pre-treatment process. THP is similar to a pressure cooker (that prepares food using steam) followed by steam explosion. In THP, the sludge is first subjected to a high pressure of 6-6.5 bar and a high temperature of 160-165 ^{0}C for up to 30 minutes. The pressurized and high temperature sludge is then suddenly exposed to ambient atmospheric pressure and temperature leading to steam explosion. Thermal pre-treatment and steam explosion disintegrates the sludge floc and improves the degradability of the sludge, by destroying chemical bonds in the cell wall and membrane of the bacteria and additionally denatures carbohydrates, lipids and proteins which become more accessible to biological degradation in downstream anaerobic digesters.

THP is a sustainable technology that coverts waste to wealth promoting resource recovery and circular economy and protects the environment and health of the nation. Using THP as a pre-treatment process for anaerobic digesters: (i) produces a pathogen-free sludge (ii) reduces the digester volume by 60-70%, (ii) increases biogas generation by 20-50%, (iii) reduces the volume of digested sludge to be disposed by 30-50%, (iv) decreases the operational cost of sludge treatment by 30-50% (v) produces a biosolid with no or little odour and (vi) reduces carbon footprint.

Recovery of Value Added Materials from Industrial and Domestic Waste

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In the past two decades, lots of effort have been carried out to develop the synthetic strategies for nanostructured materials synthesis especially with well controlled size, shape, composition and spatial arrangement [1]. Also, our world is looking for the suitable techniques to treat waste materials especially industrial waste [2]. The major hurdle in the waste treatment is cost associated with it. So, in the present meeting, I would like to highlight the strategy to extract nanostructured materials from waste product (industrial and domestic) using chemical route. The synthesis of nanostructured ternary metal oxide, carbon, high purity metal, silica, sodium nitrate, and sodium carbonate will be discussed. Ternary metal oxide, Yttria stabilized zirconia (YSZ) nanostructures were synthesized at low temperature by using simple hydrothermal route from waste zircon mineral. The morphology change has been observed by doping different mole percentage of yttria. The pure zirconia nanoparticles show spherical shape morphology whereas pure yttria shows flake like structures. The morphology of YSZ nanoparticles in the form of rods and spindle like structures was observed after addition of 3 to 8 mol % of yttria [3-4]. Nanostructured metal, silica, sodium nitrate, and sodium carbonate have also been extracted from waste using chemical techniques [5]. These nanostructures show very good photocatalytic and electrocatalytic behavior. I will also discuss the strategy to recover nanoparticles from scrap and spent battery and their applications.

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Covalent Organic Frameworks and Supramolecular Nano-Synthesis

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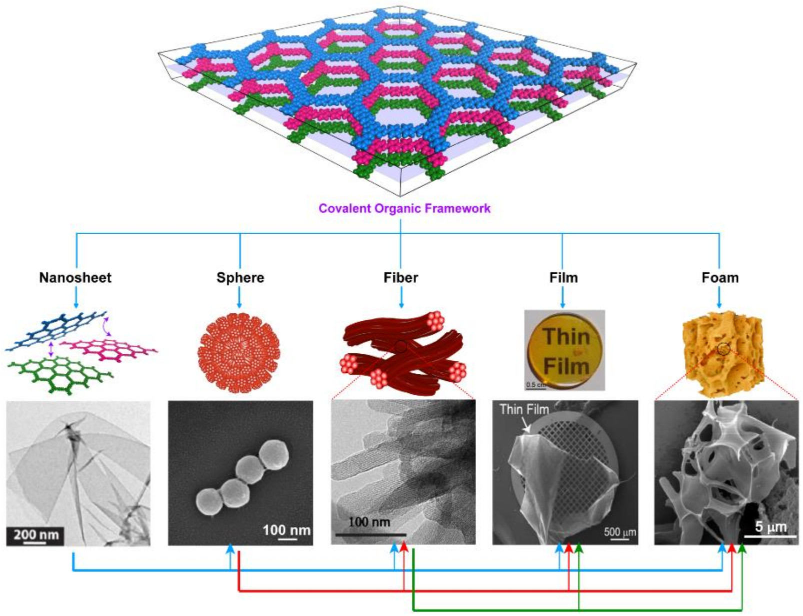
Covalent Organic Frameworks (COFs) represent a new class of highly porous, crystalline polymers with uniformly arranged ordered pore channels. Even though COFs have been used for the storage of a wide variety of molecular species like gases, nanoparticles, enzymes, and drugs, the benefits of their ordered pore channels for molecular separation are hardly extracted. The key issue behind this problem is fabricating COF particles into a self-standing, stable membrane form. Apart from the processability, the other formidable obstacle preventing the utilization of COFs in real-life applications is i) chemical stability, ii) complicated synthetic procedures and iii) scalability. In this context, we have successfully overcome the chemical stability problem of COFs, by synthesizing *β-ketoenamine* based frameworks. Irreversible enol to keto tautomerism resulted in exceptional stability within the frameworks. However, processability, synthetic hurdles, and scalability of COFs still remain unexplored. To address these critical issues, we have developed a straightforward, scalable, and novel methodology by which COFs can be synthesized by simple mixing and heating of the reactants. Using this method, COF can be processed into self-standing covalent organic framework membranes (COMs). The resultant COMs display higher porosity and crystallinity over their reported powder form. These self-standing COMs are flexible, continuous, devoid of any internal defects or cracks, show long-term durability. It retains structural integrity in the water, organic solvents, and mineral acid (3 N HCl). We have utilized these COMs for separation applications such as wastewater treatment and recovery of valuable active pharmaceutical ingredients [APIs] from organic solvents. Our result highlights that COMs could satisfactorily address the world's most challenging separation problems, including wastewater treatment and drug recovery from organic solvents in pharma industries.



Nanoporous Heptazine based Polymeric Materials for Renewable Energy Applications: Our Technological Efforts

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Heptazine based carbon nitrides are revolutionizing the field of energy and environmental remediation and particularly photocatalytic water splitting to generate H_2 [1]. The introduction of porosity resulted in enhanced activity for H_2 evolution [2]. These porous carbon nitrides (SGCN) have even shown to generate both hydrogen and platform chemicals through simultaneous water reduction and biomass oxidation, *Scheme 1* [3]. In another work, a new carbon nitride polymer with oxygen linkers (OLHP) instead of nitrogen linkers with enhanced hydrogen evolution in the visible light will be presented in detail [4]. In this line, I will discuss about our recent technological efforts in developing a prototype reactor for hydrogen production under natural sunlight. In the second part of the talk, I will briefly discuss about the Heptazine based micro-/mesoporous polymeric networks (HMPs) developed in our group for the first time for CO_2 capture and conversion [5,6].

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Carbon Capture and Utilization in Metal Industry – Outlook and Implications

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This paper highlights CO_2 capture and utilization approaches adopted in the metal industries for sustainability, with perspectives from Iron & Steel industry in India. Metal industry in India being heavily dependent on fossil fuel use, reduction of CO_2 emissions and improving energy efficiency are targeted. CO_2 capture and its conversion could lead to new chemical resources and development of new technologies, while addressing climate goals. Sustainability requires net-zero CO_2 emission status from all the nations by mid-21st century. Industries are transforming to become net-zero and contribute to climate progress. Strategic/policy actions, increased R&D investment and market deployment are vital to achieve these goals.

Metals for Solar Energy Harvesting and Carbon Dioxide Utilization

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Climate change due to excessive carbon dioxide (CO_2) is the most serious problem mankind has ever faced. Capture and then conversion of CO_2 to useful materials and fuels are the best ways to tackle these challenges. Our group has carried out several works in the field of catalysis and nanotechnology, such as DFNS [1], Black Gold [2], Defective Nanosilica [3], Solid Acids [4] and Lithium Silicates [5] to combat climate change.
In this talk, I will discuss the role of metals in solar energy harvesting and CO_2 utilization.
i) Black Gold as an Artificial Tree [2]: We transformed yellow gold to black gold, by changing the size and gaps between gold nanoparticles supported on nanosilica spheres (DFNS). Black gold harvest board band light of the solar spectrum, the entire visible region as well as in the near-

infrared region. Then, similar to the natural trees, the developed black gold acts like an artificial tree that uses CO_2, sunlight, and water to produce fuel. This work on "Black (nano)Gold" is *one-of-its-kind* and a way forward to develop "Artificial Trees" which captures and converts CO_2 to fuel and useful chemicals.

ii) Magnesium for CO_2 to Fuel and Green Cement [6]: There is an urgent need for CO_2 conversion protocols working at room temperature and atmospheric pressure, preferentially without any external energy input. Herein, we employ magnesium metal (nanoparticles and bulk), an inexpensive and eighth-most abundant metal, to convert CO_2 to methane, methanol and formic acid, using water as the sole hydrogen source. The conversion of CO_2 (pure, as well as directly from the air) took place within a few minutes at 300 K and 1 bar, and no external (thermal, photo, or electric) energy was required. This protocol can even be used for hydrogen production (940 liter per kg of Mg), which is nearly 420 times more than hydrogen produced by the reaction of Mg with water alone.

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Graphene Composite based Approaches for Water Remediation and Sensing

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Graphene has been studied for more than a decade now and has been explored successfully in various applications including solar cells, smartphones, transparent conductive electrodes, touch panels, LED, advanced composites, batteries, capacitors, paints and coatings and many more. Last couple of years have seen many advances in the field of water remediation and water quality sensing using graphene or graphene oxide based derivatives. In this talk, we will discuss graphene based water purification approaches as well as heavy metal sensing, dye degradation, water-oil separation and other related research work done at NEMO lab, IIT Bombay.

To What Extent can Biocarbon Replace Coke in the Blast Furnace?

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The scarcity of prime coals for metallurgical coke making and stringent reduction targets for carbon emissions are two main challenges facing the steel industry. Consequently, coke makers and steel producers must seek ways of lowering CO_2 emissions and decrease production costs without seriously undermining process efficiency. The use of readily available biomass materials offers the advantages of reducing non-renewable carbon emissions and reducing material costs. However, partial replacement of metallurgical or coking coals with biomass materials to produce biocoke in industrial coke ovens is limited by the deleterious effects of biomass on biocoke reactivity and mechanical strength. For example, the use of wood charcoal in integrated steelworks is limited by: (i) its negative impact on coke quality when added to coking coal blends; (ii) its low mechanical strength that cannot support the iron ore burden in large blast furnaces; (iii) its low abrasion resistance; and (iv) its ash chemistry that can accelerate its reactivity towards CO_2 in the blast furnace. Consequently, the highest amount of pristine or thermally treated biomass that can be added to a coal blend while maintaining biocoke quality suitable for blast furnace operation is typically 5 wt%.

To increase the amount of renewable carbon that can be incorporated into coking blends beyond this level, an extensive investigation has been conducted with Kraft lignin, a renewable polymer that is obtained as a by-product in the pulping industry. Kraft lignin was subjected to both torrefaction and hydrothermal carbonisation (HTC). However, the reactivity of the biocokes obtained after carbonization was high compared to that of the coke from the good coking coal and their mechanical strength was much lower than that of the coke. The high total porosity of the biocokes (>39%) and their high microporous surface areas (>400m^2/g) compared to those for the coke (27% and 145m^2/g) together with the high alkalinity indexes of pristine and torrefied lignins are the main factors that dictated the fast degradation of the biocokes under typical blast furnace conditions. In another approach, it was found that blends containing 70 wt% low rank coal, 24 wt% torrefied lignin and 6 wt% phenolic resin produced biocokes with suitable mechanical strength for handling but higher reactivity than the coke obtained from the low rank coking coal alone. The hydrochars from HTC of Kraft lignin can be added to coking coals in concentrations of over 30% without significant reductions in coke strength and reactivity. The prospects for achieving higher levels of substitution will be discussed.

Low Emission Iron and Steel Making

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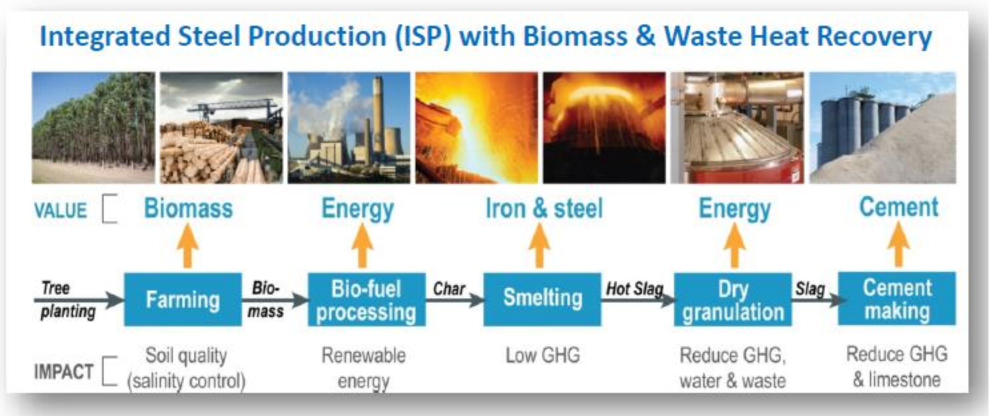
This presentation provides a summary of the progress made over 8 years of an R&D program that focused on the development of know-how and processes that could result in substantial reduction in net CO_2 emission by the steel industry. The processes that were developed covered introduction of renewable carbon and energy sources as well as minimising waste heat from processes. The status of each of the processes and application areas is provided. The use of biomass-derived fuels and reductants in the ironmaking and steelmaking industry provides a sustainable option for reducing net CO_2 emissions at a lower capital cost and technological risk compared to other breakthrough technologies under development. A key focus of this program has been to partially substitute these fossil-based fuels with renewable carbon (charcoal) from sustainable sources such as plantations of biomass species or forest wastes.

Integrated Steel Production (ISP) with Biomass & Waste Heat Recovery



Raw biomass is unsuitable for applications in ironmaking and steelmaking and should be converted into charcoal (char) through a pyrolysis process before use. A new pyrolysis process which operates continuously and autogenously has been developed and piloted. The biomass-derived chars and hydrocarbon fuels have great potential in lowering the net CO_2 emissions of integrated (BF-BOF route) steel plants. Life cycle assessment has quantified the potential reduction in net CO_2 emissions and covers cradle to gate, including plantation, harvesting, transport, pyrolysis and use of chars and bio-oil products.

The properties of chars produced by biomass pyrolysis can be tailored to each of the several applications proposed (sintering solid fuel, cokemaking blend component, blast furnace tuyere injectant, liquid steel recarburiser, etc.), thus resulting in optimal performance and greater value-in-use of the char. Our economic analysis allowed such value-in-use in applications, particularly as a replacement for BF pulverised coal injection. This analysis shows that key factors influencing the economics are the net cost of producing charcoal from biomass, selection of pyrolysis technology, value of the pyrolysis by-products, as well as the value-in-use for the charcoal. Dry slag granulation (DSG) has the potential to make a fundamental change in slag treatment and deliver a more sustainable alternative compared with the conventional water granulation process. The DSG process not only saves valuable water resources and reduces sulphurous emissions, but it may also recover a large amount of the high-grade heat in molten slag to reduce greenhouse gas emission. CSIRO has been working on the development of a novel DSG process, integrated with heat recovery, since 2002 and has made significant progress in process design and optimisation based on process modelling, laboratory investigations, extensive pilot plant trials and characterisation of the solidified product granules.

ORAL PRESENTATIONS

Structure Dependence Adsorption of Cationic Dyes over Graphene Oxide

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The presence of organic contaminants in wastewater is hazardous to aquatic and terrestrial plants and animals. Dyes are the most common organic contaminants discharged from textile effluents. These dyes are carcinogenic and mutagenic; thus, removal of these dyes is desirable. The adsorption process is primarily used for removing these dyes; graphene oxide (GO), due to its hydrophilic functional groups is used vastly as adsorbent. GO has oxygen functionalities with negative charge; thus, it is most suitable for removing cationic dyes. However, the adsorption of different cationic dyes over GO varies based on their molecular structure. In this work, we have studied the adsorption behavior of cationic dyes such as Azure A, Azure B, Rhodamine 6G (Rh 6G), and Malachite Green (MG). The adsorption capacity was reduced for larger structures of Rh 6G and MG; pseudo second-order was followed with a better fit in kinetics analysis. Freundlich isotherm was a suitable isotherm model showing heterogeneous adsorption. The maximum adsorption capacity of 68.45 mg/g, 81.24 mg/g, 63.28 mg/g, and 60.50 mg/g was found for Azure A, Azure B, Rh 6G, and MG. These studies will give better insights into underlying interaction of cationic dyes and GO.

Bauxite Residue Management by Leveraging Technical Advancement for Optimal Land Usage towards Sustainable, Environmental Friendly Operations

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With decreasing quality of bauxite being processed in Bayer plants and the drive for increasing production, stress on the mud circuit operation and environmental friendly storage of bauxite residue is a major challenge for today's alumina refineries. To facilitate the same, modern day thickeners have evolved from the earlier conventional settling tanks to the high rate decanters (HRD) and deep cone washers (DCW). These high rate decanters and deep cones meet the objective to process bauxite residue with high compaction, with minimal residence time to improve the separation efficiency.

At UAIL (Utkal Alumina International, Ltd.), the Indian east coast bauxite (Baphlimalli Mines) is digested at medium temperature to extract alumina and the bauxite residue is processed through a Counter Current Decantation (CCD) circuit consisting of HRDs and DCWs before the residue is dry discharged to the residue disposal area via pressure filters.

Usage of synthetic polymers enhances the solid settling. Choosing a right flocculant for the regional bauxite to be processed enables reduced variations in the circuit. Customized flocculant application is imperative to achieve the desired settling rate for a compact underflow and clear supernatant liquor.

The successful commissioning and ramp up of the Red Mud Filtration (RMF) unit in three months enabled 100% dry disposal, thus contributing immensely in reducing the liquor soda losses, optimal usage of land and improve the stability of the pond, by reducing the hydraulic thrust on the embankment dykes.

This paper highlights the efficient bauxite residue processing at UAIL, by debottlenecking the mud circuit to enable processing of low THA bauxite (than design). Substantial gains were achieved in terms of sustaining higher production rates, reduced chemical soda losses, and optimal flocculant consumption. This paper also describes the impact of introducing dry residue disposal and residue management for the refinery.

Keywords: Dry Bauxite Residue disposal, Bayer's Process, Decantation, Flocculant, Pressure Filtration & Environment.

Efficient Reutilization of Solid Waste at JSPL, Raigarh

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The integrated steel plants, in general, produce large amounts of solid waste during the iron and steel making process. This solid waste has many valuable products, which can be reused if recovered economically. The stacking and discarding of solid waste occupies a huge space, resulting in a waste of resources and health hazards. Discarding waste generated is not an easy task and proper reutilization is needed to reduce the same efficiently. Many steel plants worldwide have already adopted innovative measures to utilize these waste products with an objective of improving the operational efficiency and economics of steel industries.

To recover value from waste, Jindal Steel & Power Limited (JSPL) Raigarh reutilize it in the plant processes efficiently and are fully committed to safeguarding the environment around its various plants and mines. Towards this direction, JSPL has adopted 4 'R', namely Reuse, Recycle, Reduce & Recover strategy to convert waste into wealth. Also, a systematic procedure has been made to identify and segregate solid wastes. These wastes often have enough carbon content, gross calorific value, Fe content, gangue content, etc. Due to these characteristics, they can be used as input materials in place of natural minerals. Hence, primary material input reduces with the efficient utilization of waste materials. Present study highlights the wastes generated in the coke oven plant and coal-based DRI units. The prime category of wastes generated through these units is settling coke fines, DRI char, accretion, ABC dust, etc. By effective utilization, JSPL Raigarh unit uses approximately 75% of these waste materials as input material for power generation, fly ash brick manufacturing and silicomanganese production. This article also discusses the issues pertaining to solid waste generation in terms of volumes, challenges and efforts towards recycling and utilization in critical plant applications with its proper management.

Keywords: Solid waste, management of solid waste, recycle, reutilize.

Effect of Extrusion on the Physical and Mechanical Properties of Briquette made with Composite Fines of Blast Furnace Flue Dust and Iron Ore Fines

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In this study, the extrusion of reduced blast furnace composite fines at elevated temperatures allows manufacturing final products with distinctive microstructure and mechanical properties. The experimental results of extrusion of the composite powder under different laboratory conditions are presented and analysed. The main objective of the study is to demonstrate that blast furnace flue dust fines can be consolidated to highly dense products through extrusion. Reduced blast furnace flue dust and iron oxide fines were compacted at 100 MPa pressure to produce briquettes of 2 cm and 4 cm diameter and height respectively. This compacted material was subjected to different heat treatment temperatures of 1373 K and 1473 K. The product after heat treatment was extruded by extruded press at different pressures of 175 MPa and 240 MPa respectively. The mechanical properties such as density, compressive strength, hardness and microstructure of the final product have been measured and reported. Quantitative and qualitative metallography has been applied within the extruded product to match with the values of the mechanical properties of the structural steel used. The product achieves density of 7.51 gm/cm^3 after extrusion of the heat-treated samples at 1473 K and extruded pressure of 240 MPa. Furthermore, the compressive strength and hardness values at the same conditions are 336.44 MPa and 117.42HV20 respectively. The product obtained can be used for structural purpose. Thus, the waste materials or the by products from blast furnace can be used for a specific purpose and enhance the economy of the industry.

Removal of Hexavalent Chromium from Chrome Plating Wastewater- A Coprecipitation Technique

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Hexavalent chromium (Cr (VI)) is a toxic-heavy metal usually generated during industrial processes involving steel production, chrome pigment and ferrochrome production and chromium plating. Cr (VI) having a mobile characteristic can easily penetrate the cell wall and exert its carcinogenic and noxious influence on the cell. So far, several studies have been done in Cr (VI) remediation, mostly reporting methods such as adsorption, reduction and RO-filtration, ion exchange, foam flotation and electrolysis.

In the present study, a novel technique for in situ reduction and removal of hexavalent chromium from chromating and chrome plating wastewater was developed. Cr (VI) remediation was achieved in two steps by directly reducing toxic Cr (VI) into less toxic or nontoxic Cr (III) and removing it. The first step involved the addition of solid $FeSO_4$ (purity of 95 – 97%, industrial grade) directly to the waste solution while maintaining the pH level at 2-3 at the time of addition. The resulting liquid was allowed to stand for coagulation. Upon further investigation, it was observed that a Cr (IV) removal efficiency of 80 to 90% could be achieved in this stage through simultaneous reduction of hexavalent to trivalent chromium and its precipitation via iron coagulation. Furthermore, in the second stage, the remaining 10 to 20% chromium was removed as $Cr(OH)_3$ by treating the resultant solution with 20% NaOH (w/v).

From a practical standpoint, this in-situ method of Cr (VI) remediation with solid crystalline ferrous sulphate without involving alkali to remove 90% of chromium along with iron precipitate shows promising potential for extensive applications in the field of wastewater management.

Studies on Replacement of Sodium Hypochlorite with other Chemicals for Cyanide Reduction in Coke Oven Effluent

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Effluent generated from coke oven during coal carbonization process and cleaning of coke oven gas contains lot of pollutants such as ammonia, phenol, cyanide, tarry material, oil & grease etc. These can cause a serious damage to living beings when discharged to the environment. These pollutants are, therefore, treated before discharge/recycle primarily by biological process after some physico-chemical pre-treatment steps.

In Coke Oven Effluent Treatment Plant (COETP), due to inherent limitations of biological treatment process, tertiary treatment is often carried out by using sodium hypochlorite as treatment agent for achieving the norms of cyanide. Considering that cyanide treatment by sodium hypochlorite is costly, a study was undertaken to reduce overall cost of treatment by other chemicals.

A lab scale study with COETP influent was carried out to identify efficacy of select chemicals like ferric chloride and ferrous sulphate for reduction of cyanide in COETP influent. Lab scale study showed that significant amount of cyanide can be reduced by adding small quantity of ferric chloride or ferrous sulphate. Based on the lab scale results pilot scale trials were carried out by dosing ferric chloride and ferrous sulphate as pre-treatment agent at equalization tank, before biological treatment, of COETP.

Through pilot studies, it was established that dosing of 2.5 to 3 kg per day of ferric chloride or ferrous sulphate was able to reduce cyanide concentration of COETP influent to a significant extent i.e. upto 80 and 83 % respectively. Since this treatment is not detrimental to biological treatment by activated sludge, it opened up the possibility of reduction of sodium hypochlorite consumption in tertiary treatment, when necessary.

Cold Briquetting of CRM Oily Sludge for in house Utilisation

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Integrated steel plant generates substantial amount of iron and carbon rich process wastes right from ore beneficiation to steel rolling operations. JSW Steel Ltd., Vijayanagar works is having unique and excellent facilities such as tailing beneficiation plant, mill scale briquetting, micro pellet plant and iron recovery plant, which recycles various types of waste sludge and dust. Though a major part of the solid waste is recycled, cold rolling mill (CRM) oily sludge is still not being utilized. CRM unit generates around 5 tons of oily sludge every day, which contains 35-40% oil, 20-25% Fe, 20-25% C and 8-10% moisture. The oily sludge is basically ester based triglyceride with a pungent smell. It is difficult to store and transport this sludge, as it generates methane and hydrogen through anaerobic fermentation. The present work describes a method of making agglomerates of CRM oily sludge by adding suitable oil absorbing materials along with organic and inorganic binders. These agglomerates produced were tested physically and chemically and found suitable for handling with desirable properties such as drop number, moisture and CCS. The agglomerates may find applications in coke making and sintering.

Introduction of Improved Bottom Quenching Facility for Combined Coke Quenching in Quenching Wagon

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In combined coke quenching, water is sprayed on hot coke from both top and bottom. Quenching tower (QT) of coke oven battery (COB) under the current work is having top quenching facility only. Initially, the installed quenching water supply system at QT had provision for combined coke quenching and therefore quenching wagon had the bottom quenching facility for spraying water from bottom of hot coke. Due to practical issues, bottom quenching facility installed in quenching wagon was discontinued and bottom quenching water supply lines coming from quenching water pump house had been isolated at QT. Presently the

water spraying only for top quenching is for 130 sec.
In the current work, an improved system has been introduced in which water pumping facility for bottom quenching is incorporated at each side of quenching wagon. The system consists of two suitably sized pump-motors having minimum flow and head requirement with two modified water tanks, one set at each side of the quenching car that has been installed. Pump discharge is connected with existing water distribution main header at quenching wagon and pump suction is connected with modified water tank. Isolation valves of bottom quenching water supply lines at QT were opened with approximately 20% opening allowing bottom quenching water into the tanks. Water from the tanks is then pumped for spraying at the bottom of hot coke simultaneously with water spraying on top. The required electrical power to the pumps is provided from the electric loco and pumps are operated from loco pilot cabin.
The upgraded and modified facility helped in addressing inadequate water pressure issues, reduced total quenching time to 110 sec and led to improved coke quality by reducing average coke moisture by 2–3%.

Keywords: Coke, Coke moisture, Combined Quenching.

Production of Bio-coal by the Hydrothermal Carbonization of Biomass

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Hydrothermal carbonization (HTC) is an induced coalification process that converts raw biomass into a coal-like product, called hydrochar, characterized by high carbon content and high calorific value. This type of thermo-chemical conversion, also referred to as wet pyrolysis can be applied to a variety of non-traditional sources such as the organic fraction of municipal solid waste, wet agricultural residues, and sewage sludge. Unlike traditional dry pyrolysis, the HTC process allows for the treatment of substrates with elevated moisture content, up to 50-70%, without requiring a drying pre-treatment step. In this study, three different types of biomass such as bamboo, wood and food waste were analysed. Lab-scale studies were carried out in a pressure vessel in the temperature range of 180-250 °C under autogenous pressure of 10-15 bar. The products obtained are a solid material called bio-coal with a mass yield ranging of 50-70% and aqueous by-product containing organic acids dissolved from the biomass during the treatment. The atomic C/O and C/H ratios of the obtained bio-coal decreased with increase in reaction temperature and were found to be like lignite coal. The bio-coal produced at optimum reaction conditions of 250°C had a calorific value of approximately 20–25 MJ/kg. The solid bio-coal can be used for a variety of

applications such as soil remediation, activated carbon or as a low carbon fuel source.

Utilization of EAF Slag in Concrete in Place of Natural Aggregate

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AM/NS India has iron and steel making furnaces which produces around 0.6 MT blast furnace slag and around 1.6 MT EAF/Conarc Steel making slag per year. Disposal of slag is one of the biggest environmental concerns and the study aims to valorize the slags. Ground Granulated Blast Furnace Slag (GGBFS) has a well proven application as a substitute to cement in concrete, its replacement ratio is in the range of 25 to 75% subject to quality. EAF/Conarc Steel slag mainly contains gangue minerals like alumina, silica, calcium oxide, magnesium oxide, iron oxide, etc. In the current study, an attempt has been made to achieve 100% replacement of cement by GGBFS in concrete by alkali activation. Second, steel slag is used to replace 100% natural fines and coarse aggregates in concrete. Alkali activated concrete (M15 and M30 grade) was prepared by this method. Experiments were conducted with 100% cement replacement with GGBFS using alkali activators like sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH). From the study, it was observed that the strength of concrete increases 1.5 times in the experimental test blocks when all the aggregate is replaced with slag aggregate and 100% GGBFS as binder producing a low-cost cement free concrete made using by-products from the steel plant.

Improved Burner Efficiency of Soaking Pits at Alloy Steel Plant, Durgapur

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Alloy Steel Plant (ASP) at Durgapur is provided with 12 soaking pits in its Blooming & Billet Mill

for heating ingots before rolling to blooms or billets. Each soaking pit is provided with a dual fuel burner, firing either Coke Oven (CO) gas or oil. The designed maximum flow rate of CO gas of about 4200 kcal/Nm^3 Net Calorific Value (NCV) is 750 Nm^3/h. Availability of CO gas at ASP has reduced in the recent past leading to introduction of Coal Bed Methane (CBM) gas of 8400 kcal/Nm^3 NCV as fuel. However, as there were only 2 possible fuel streams to be connected to the burners – one gaseous and the other liquid, CBM gas was being conveyed to the burners through the same CO gas pipeline, without mixing the two. This led to improper combustion of CBM gas, whenever fired, resulting in inefficient heating of stocks.
A new CBM gas nozzle with the same heat load was designed, fabricated and installed in soaking pit #1 to increase heating efficiency of the stock. The modifications included removal of existing dummy pipe along with oil gun and insertion of a separate CBM gas nozzle in its place. Thus, provision was created for separately firing CBM gas and CO gas. The necessary additional equipment/instruments needed for efficient firing of CBM gas through modified dual fuel burner were also installed. No modifications were carried out in the combustion air system for firing with either CO gas or CBM gas though modified dual fuel burner. The result indicates a reduction in specific fuel consumption by about 14.6 % through above modifications, while firing with CBM gas.

Energy Efficient Composite Lining for BF Tuyere stock System

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Generation of hot molten metal from blast furnaces (BF) is a highly endothermic process. Total surface area and hence energy loss of tuyere stocks is higher than any other component of hot blast system (HBS). Energy lost by dissipation would have to be additionally supplemented by extra

fuel, in turn, adding to the cost. Tuyere stock refractory lining must be able to withstand high pressure and abrasion and yet have low thermal conductivity. This would prevent heat loss from hot blast. However, a single refractory material having all of these properties doesn't exist. So, all tuyere stocks of all blast furnaces opt for a higher-grade refractory material to withstand pressure and abrasion, compromising on heat loss as these materials have higher thermal conductivity. Hence, since ages, we have been losing energy. The team developed a composite lining of foam based insulation and silicon carbide that could reduce surface heat loss by 40%. Basic objective of the invented lining design of blast furnace blow-pipe is to create more reliable and safe blow-pipe design in which drawback of existing design can be removed. Advantage of this developed design is that spalling/cracking tendency of refractory castable of existing design is overcome by use of silicon carbide tube. Probability of spalling/cracking during operation is very less in case of silicon carbide tube because of its high strength and high thermal conductivity. Use of customized PCPF insulation block as back up lining results into significant reduction of shell temperature. Shell temperature has been estimated to be about 180 °C.
Besides improving the reliability of tuyere stocks, this newly developed blowpipe refractory design would reduce the carbon footprint of blast furnaces using this technology.

Use of LD slag in BOF Converters of Rourkela Steel Plant to increase Heat Weight and Reduce Total Metallic Input

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Reuse of waste in integrated steel plants is important with regards to environmental and economic consideration. Slag generated from basic oxygen converter (LD slag) is one of the recyclable wastes in integrated steel plants. LD slag at Rourkela Steel Plant (RSP) is being generated at the rate of 140-160 kg per ton of crude steel. Due to its high metallic value (FeO~24%) and lime content (CaO~45%), it is possible to use it in BOF converters for partially replacing fluxes and iron recovery. It also acts as a coolant and can be used to replace scrap to some extent. Recovery of iron leads to increase in heat weight and reduction in total metallic input (TMI) of the BOF Converter. However, the high P_2O_5 content makes its use challenging in steelmaking.
RSP has endeavoured to segregate the LD slag in size range of 20-40 mm and charging it in converters of Steel Melting Shop-II as a means of waste utilization. To facilitate its use, a number of logistic improvements and tuning of blowing practices were carried out. The shop has started using LD slag in converters in the tune of 17 kg per ton of crude steel. The blowing practices were

modified to accommodate higher level of iron ore addition during blow along with the LD slag. Fine tuning of LD slag addition in convertors of steel melting shop opened the path for waste to wealth in terms of recycling of LD slag for in-house consumption. Recycling of LD slag along with iron ore addition also resulted in increase of heat weight and reduction in TMI.

Keywords: Basic Oxygen Furnace, LD slag, flux, Total Metallic Input, Heat Weight.

Dissolution of Rare Earths Coal Fly Ash using Deep Eutectic Solvents

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Rare Earth Elements (REE) have emerged as vital elements for various technologies useful for reducing carbon footprint [1]. Presently REEs are leached industrially from respective minerals using inorganic acids. The processes employed for REE leaching/dissolution are very energy intensive as well as environmentally unfriendly [2]. The increasing demand for some of the rare earth metals and rising concerns to avoid environmental damage have led to research for alternate processes including use of chemicals which are compatible with nature. Solvo-metallurgy (SM) is an emerging branch of metallurgy which offers all the attributes of hydrometallurgy along with the additional benefits in terms of environmental aspects. SM utilizes ionic liquids (IL) as well as deep eutectic solvents (DES) for resource dissolution and also in separation stages [3]. The paper discusses results of SM studies utilising DES leaching of rare earth elements (REE) from lignite-based coal fly ash containing about 0.2% REEs with one third of them being valuable heavy rare earths. Two different DES were synthesized characterised and different leaching parameters viz. reaction time, temperature, liquid to solid ratio and water dilution were studied. These studies have shown scope of leaching about 90% of REE values with appropriate combination of hydrogen bond donor (HBD) in DES.

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Quasicrystalline Alloys for Energy Application

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Quasicrystals contain catalytically active elements and are stable at high temperatures and thus have the potential to be used as catalysts where high thermal stability is necessary. Because of their complex nature, it has been difficult to gain atomic scale understanding of the catalytic activity of leached quasicrystals. Additionally, the role of underlying quasicrystals in the catalytic activity is yet to be understood. In order to achieve this information, we have attempted to create a simple model catalyst of nanoparticles on quasicrystalline surfaces by leaching well defined surfaces of single grain quasicrystals. As the first step of these studies, we present here the effect of leaching treatments on surface morphology and chemical composition of different Al-based quasicrystals studied by scanning electron microscopy (SEM), energy dispersive x-ray (EDX) analysis and x-ray photoelectron spectroscopy (XPS). The high symmetry surfaces of single grain icosahedral (i)-Al-Cu-Fe and decagonal (d-) Al-Ni-Co, (d)Al-Cu-Co quasicrystals and a polygrain (i)-Al-Pd-Re, (i)-Al-Cu-Fe, (i)-Al-Pd-Mn quasicrystal with random surface orientation were leached with NaOH solution at varying times and the resulting surfaces were characterized by scanning electron microscopy, energy dispersive x-ray analysis and x-ray photoelectron spectroscopy. The leaching treatments preferentially remove Al producing nano-particles of the transition metals and their oxides. The leached fivefold surface of i-Al-Cu-Fe exhibits micron sized dodecahedral cavities on which the nanoparticles are precipitated. However, no specific microstructure has been observed on the tenfold surface of d-Al-Ni-Co and the polygrain i-Al-Pd-Re. Quasicrystalline surface can be regained after polishing the leached layer, indicating that leaching occurs only in a limited depth from the surface. The 2-hour leached as-grown and mechanically activated Al-Cu-Fe alloys was subjected for catalyst application in hydrogen storage materials. The catalytic effect of leached alloy on the de/rehydrogenenation characteristics has been studied. The hydrogenation behaviour including absorption kinetics will be discussed and presented in detail.

Enhancing Solid Waste Utilization through Sintering Operation

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Waste materials, mainly in the form of micro-fines are generated in all process of steel plants from primary zone (like BF flue dust, BF slag etc), secondary process (BOF slag, BOF sludge) to finished product area (Mill Scale). Although part of the generated fines is recycled in existing agglomeration process viz. sintering, most of it is still unused. The use of micro-fines in sinter bed is very limited because it affects the permeability of bed and reduces productivity. Also, Bhilai Steel Plant (BSP) of SAIL has recently installed a slime beneficiation unit of 1.2 MTPA throughput at Dalli mine head. The unit enriches the quality of slime to 64% Fe content and this finely grained concentrate is being used in sintering operation. This increases the fine ore percentage in sintering and reduced bed permeability. Preparation of micro-pellet using these waste materials as well as beneficiated slimes and their consumption through sintering route was tried on lab scale. Sintering raw materials, metallurgical waste and beneficiated fines were received from BSP. Micro-pellets of adequate strength were made with waste materials and beneficiated fines with suitable binders. To study the effect of micro-pellet addition on sintering parameters by simulating sintering condition as per BSP, pot sintering experiments were conducted with variations in micro pellet addition by 0%, 2%, 3%, 5%, 7% and 10% (wt% of sinter mix charge). Pot test results indicate that, with increasing micro-pellet addition, no significant deviation in specific productivity of sinter is observed up to 5% (Fig. 1). Yield of the product (wt% of +5mm sinter) shows initial increasing trend up to 3%, followed by significant decrease after 5% addition. Cold strength of sinter in terms of drum tumbler index (DTI) slightly decreases with increasing micro-pellet proportion (Figure-2). Hence, it was concluded that addition of micro-pellet from 5 wt% onward of sinter mix charge has shown drastic deterioration in sintering parameters.

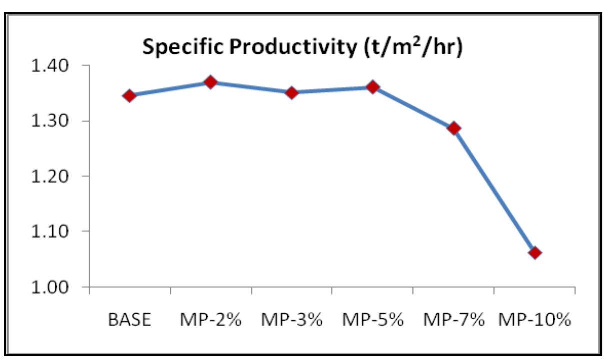

Fig.1: Variation of specific productivity with increasing micro-pellet addition rate

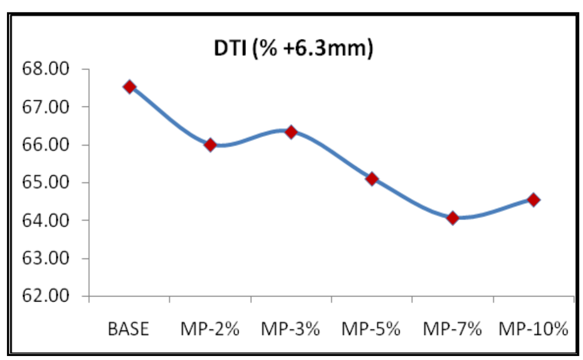

Fig.2: Variation of DTI with increasing micro-pellet addition rate

Keywords: Iron ore sinter, Micro-pellet, Specific productivity

Investigating Microstructural and Microchemical Effect of Ageing on Cu-Rich Phase of Super 304H SS Exposed to Chloride Environment

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SS 304H Cu (18Cr-9Ni-3Cu-Nb-N) is chosen as a candidate material for superheater and reheater tubing of advanced ultra-supercritical (AUSC) boiler applications for achieving higher thermodynamic efficiency by operating at temperatures and pressures of 710 °C and 720 °C respectively which are significantly higher than sub-critical (conventional) and supercritical power plants. In the present study, efforts have been made to assess pitting corrosion behavior of SS 304HCu prior and after aging for 20000 h, 10000 h and 5000h at 973K to simulate the operating conditions of about 2 years and 1 year respectively. However, prolonged exposure of these alloys to high temperatures during service could lead to Cu precipitation, whose role on corrosion properties needs an investigation. Critical pitting potential (E_{pp}) decreased with ageing. The parameters indicating passive film stability measured by EIS revealed faster passive film dissolution as indicated by low polarization resistance in aged condition. The EIS results correlated well with the variation in the respective E_{pp} obtained from the potentiodynamic polarization diagrams. Microstructure and morphological variations in thermally aged specimens were used to explain the above variation in the corrosion properties.

Study of semiconducting to metallic transition in calcium doped Sr_2TiCoO_6 double perovskites thermoelectric materials

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The present work illustrates the structural and thermoelectrical properties of Sr_2TiCoO_6 (STC) double perovskites. Environment friendly rare-earth free $Ca_xSr_{2-x}TiCoO_6$ $(0.0 \leq x \leq 0.3)$ (CSTC) ceramics were synthesized using solid state synthesis route. CSTC ceramics were found to possess a cubic crystal structure with $Pm\bar{3}m$ space group, as confirmed by Rietveld refinement of XRD data. The morphological study was carried out by SEM and energy dispersive x-ray spectroscopy. The temperature-dependent electrical conductivity and thermopower of these oxides showed the semiconductor to metal transition at around 700K[1]. X-ray photoelectron spectroscopy (XPS) confirmed the presence of multiple oxidation states of Co and Ti, creating defect sites in these oxides. CSTC ceramic samples exhibited a positive Seebeck coefficient implying p-type behavior[2, 3]. The charge transport mechanism of all the CSTC samples was found to be governed by a small polaron hopping model.

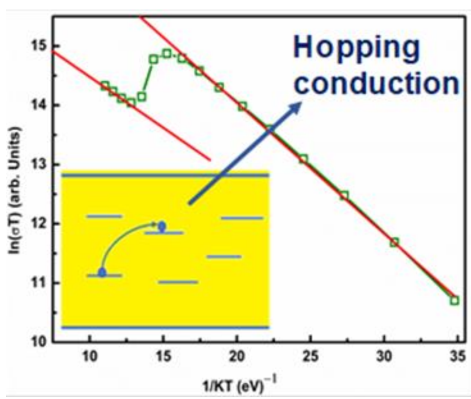

Figure 1:Polaron hopping conduction of Ca doped STC ceramics

Keywords: Thermoelectrics, Conductivity, Thermopower, X-ray Photoelectron spectroscopy, Seeback Coefficient, Polaron hopping

POSTER PRESENTATIONS

Fluid Flow in Modified Graphene Foam for Water Purification: A CFD Approach

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Permeability of fluid flow in spongy structures is vital and governed by transport phenomena in porous media. Recently, simulation of fluid flow through porous medium has received attention for contaminant removal in water treatment application. In this study, computational fluid dynamics (CFD) was employed for simulating fluid flow distribution in porous structures to predict pressure drop of the flow as a function of the pore-size distribution. CFD modelling with the help of ANSYS-FLUENT was used to estimate permeability with different pore-sizes by varying compositions of graphene in composite foam. It was further compared with theoretically predicted values using Darcy's law. Analysis of variation of parameters on 2-D model meshing followed by an investigation of the three-dimensional foam geometry was done. Pressure drop for this material was computed using the finite volume method (FVM). This study helps to understand the influence of pore size variation on the pressure drop for modified graphene foam material with tunable porosity. Fluid velocity and porosity will help to understand the solvent flow for sorption of organic compounds in porous foam for treatment of wastewater.

Keywords: Pressure drop, Permeability, CFD, Simulation, Darcy's law, Graphene foam, Porous media.

Synergistic Degradation of Dye with Marine Bacteria Incubated in Graphene Oxide Matrix

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Graphene or graphene-based nanomaterials have emerged as novel scaffolds for developing robust bio-catalytic systems and a fast-developing promising contender for bioremediation. The interaction of bacteria and graphene is such an elusive issue that its implication in environmental biotechnology is unclear. The complexity and recalcitrant nature of the dyes make the conventional techniques inadequate and remain a challenge for industrial effluent treatment. Many scientists have developed hybrid processes and hybrid materials to enhance the treatment processes to satisfy increasingly stringent laws and criteria related to effluent discharge. The current study explicitly focuses on immobilization and growth of dye-degrading marine bacterial isolates on graphene oxide and their application in methylene blue dye degradation. The synergistic effects of adsorption and biodegradation achieved a unique clean-up performance that the counterpart-free bacteria could not fulfil. Further, toxicity analysis of intermediates also confirmed the non-toxic nature of the intermediates formed after synergistic treatment. This work has the potential to lead to zero effluent treatment processes.

Utilization of Cow Dung in the Reduction Roasting of Iron Ore in Hybrid Microwave Furnace

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The reduction of iron ore using cow dung has introduced a new era because of its contribution to energy and emission reduction. Cow dung (fixed carbon: 9.33%, volatile matter 43.68%) is used as the reductant in the reduction roasting of iron ore in a hybrid microwave furnace with a frequency of 2.45 GHz and maximum power of 4 kW. The optimum conditions of roasting as determined by Taguchi statistical design were found to be: temperature of 900 ºC, time of 5 minutes and reductant to feed ratio of 0.4. The magnetization of microwave treated samples was determined using vibrating sample magnetometer (VSM). Characterization studies indicate the

formation of magnetite phase under optimum conditions resulting in higher total magnetism saturation of the sample. The magnetic susceptibility and saturation magnetization of lean iron ore using cow dung as reductant is very effectively enhanced by converting hematite to magnetite at the optimum condition using a controlled hybrid microwave furnace.

Keywords: Lean Iron Ore, Hybrid Microwave furnace, Cow dung, Reduction roasting, Saturation magnetization.

Sustainable Recovery Techniques for Precious and Valuable Metals from Urban ores: Gold, Silver etc.

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Metal consumption and production is always regarded as one of the prime indices of any nation's economy. The demand for metals has been increased considerably over the years, resulting in severe environmental stress due to their extraction methods. In recent times reclamation of metals through urban ore has gained much popularity mainly due to rapid advancement of technology. Recovery of metals from urban ores have been proven to be profitable and environmentally more attractive deal. However, recycling of urban ore is challenging in several aspects notably with respect to toxins and acidic effluent generated through the existing techniques of recycling. In this regard, a sustainable recovery technique is required to process these urban ores. The present paper shows potential of bacterial leaching for sustainable recovery technique using bacteria or fungi for precious and valuable metal extraction from urban ores.

Keywords: Recycling, Urban ore, electronic waste, Bioleaching.

Effect of Tetrahedral Site Doping of Ni-containing ‘Layered’ Transition Metal Oxide on the High Voltage Structural and Electrochemical Stability as Cathode Material for Li-ion batteries

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The development and understanding of transition metal (TM) based oxides for applications in electrochemical energy storage, *viz.*, essentially for the next generation alkali metal-ion battery systems, has incentivized the research on materials development. Less Co containing or Co free, Ni containing ‘cation ordered’/layered Li-TM-oxides, as a cathode material for Li ion batteries, suffer from structural instability due to ‘TM-migration’ from the TM-layer to the Li-layer upon Li-removal (*i.e.*, "cation disordering"), especially at deep states of delithiation at high cell voltages (typically beyond ~4.2 V vs. Li/Li^+). Such structural instability causes mechanical instability, significant impedance build-up and fade in Li-storage capacity, thus limiting the cell voltages to ≤ 4.2 V for stable operation. The deleterious ‘TM(Ni)-migration’ pathway involves the vacant tetrahedral site (t-site) of the Li-layer as the intermediate crystallographic site. Therefore, we explored here the possibility of supressing the ‘Ni-migration’ by ‘blocking’ the t-site with a cationic dopant that is stable at that location; *viz.*, possibly a d^{10}/d^0 TM-ion. In this regard, our simulations based on density functional theory revealed that the concerned t-site is an energetically favoured and stable site for d^{10} Zn^{2+}. The same was supported by a detailed analysis of the crystallographic data (including bond valence sum) obtained with the as-prepared Zn-doped Li-NMC, with Zn-ions substituting for Li-ions (*i.e.*, $Li_{0.9}Zn_{0.05}Ni_{0.33}Mn_{0.33}Co_{0.33}O_2$ composition). The simulations also predicted that, as hypothesized, Zn-doping is likely to prevent ‘Ni-migration’ upon Li-removal. In agreement with the above, upon being subjected to long-term galvanostatic cycling using a high upper cut-off voltage of 4.7 (vs. Li/Li^+), the Zn-doped Li-NMC exhibited significantly improved cyclic stability, near-complete suppression of ‘cation mixing, and negligible build-up of impedance (as well as potential hysteresis), as compared to the un-doped counterpart. From a broader perspective, such subtle tuning of the composition-structure can potentially be extended to other TM-oxide based materials, including the very high Ni containing Li-TM-oxide cathodes; rendering them structurally stable at very high cell voltages and, thus, leading to the successful development of high capacity and high voltage cathodes, possessing good long-term cyclic stability, for the next-generation Li-ion batteries.

A Successful Conversion of Spent Graphite Material into Value Added High Quality Graphene Oxide for Symmetric Supercapacitor Application

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Graphene oxide (GO) has been successfully prepared by modified Hummers method and spent graphite material from expired LIBs is used as the source for GO preparation. During the GO synthesis, all the unwanted heavy metals are entirely removed from graphite thereby eliminating the curing step of graphite. The recycling of LIBs promotes the waste to wealth policy and sustainable energy resources and reduces the environmental hazards. The several physical and electrochemical properties of reclaimed graphite and as-prepared GO materials have been studied by experimental analytical methods including XRD, Raman, SEM, TEM, and CV, GCD analysis. The enlarged value of lattice d-spacing, phase purity and characteristic peak for the both regenerated graphite and graphene oxide materials is monitored from XRD results. As found from TEM output, high-quality graphene sheets are clearly seen and length of the individual sheet is found to be 100 nm. As-prepared reduced graphene oxide exhibits the electric double layer capacitor (EDLC) behavior and shows the superior specific capacitance of 170 F/g. The symmetric EDLC device has been fabricated with GO electrode and demonstrates excellent charge storage properties in terms of energy and power density.

Keywords: spent device, graphite, graphene oxide, electrochemical storage, waste to wealth.

Utilization of Ferrochrome Slag (FCS) in Synthesis of Geopolymer Composites: A New Avenue for Sustainable Solid Waste Disposal

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The ferrochrome slag (FCS) is a by-product of the ferrochrome industries that is generated during

the production of high/low carbon ferrochrome (FeCr) alloys. It is estimated that nearly 1.1 to 1.5 tons of FCS is produced for the production of 1 ton of FeCr alloy. Considering current global production and the future demand for the FeCr alloys, it is a big challenge for sustainable disposal of this waste. The key challenge for the safe disposal of FCS is its high chromium content (>9 wt%). Hence, there is a possibility of leaching hexavalent chromium into the environment which can lead to several health hazards. On the other hand, owing to the rapid infrastructure growth, the use of cement-based materials in construction is increasing exponentially. The production of cement is both an energy and resource intensive process that has one of the highest contributions to anthropogenic carbon emission (≥7%) prompting global warming. Therefore, it is high time to find alternatives to cement, and FCS is one of the potential alternatives. The presence of silica, alumina and magnesia in FCS is helpful for its conclusive use in the production of geopolymer composites (cement-free materials) for various building material applications. In this study, FCS is taken as a binder in geopolymer composite preparation along with sodium-based alkaline activators. A mixture of sodium silicate and sodium hydroxide solution is used to activate the FCS and river sand is used as aggregate. All the developed composites are being cured at ambient temperature and the optimum composition attained a compressive strength of 20 MPa with addition of 15% of BF slag which could be used for various construction applications with low load requirements.

Keywords: Ferrochrome slag; Geopolymer composite; Cement-free materials; Waste utilization

Al-Bi-Graphene-CNT Composites for Rapid H_2 Generation through Water Splitting

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Activated Aluminium (Al) composites readily react with water and generate hydrogen at room temperature. Theoretically, when 1 g of Al reacts completely with water, it generates ~1360 ml of hydrogen. To improve the hydrolysis reaction, Al is combined with additives during ball milling. Bismuth (Bi) has attracted greater attention as an additive due to its low price and catalytic performance. Due to the difference in the standard reduction potential value of Bi (0.308 V) and Al (-1.662 V), micro galvanic cells are formed in Al-Bi composite. Milling Al-Bi composite with

graphene sheets enhanced hydrogen yield and generation rate. High specific surface area of graphene is expected to create a new active surface for hydrolysis. Graphene is expected to form multi-layered structure in Al particles of Al-Bi composite. When carbon particles are desorbed from Al matrix during hydrolysis, new Al is exposed resulting in increased reaction rate. Activation of Al-Bi composites by adding carbon nanotubes (CNTs) showed enhanced hydrogen generation rate and conversion yield for Al-7.5 wt% Bi-5wt% CNT. The CNTs can effectively control the agglomeration and fill the gaps between Al particles. CNTs form micro galvanic cells with Al, and in addition, good electrical conductivity enhances the hydrogen generation yield. Moreover, water flowing through CNTs has a higher flux and confinement effect of water inside CNTs decreases the chemical potential of water. The current work focuses on structural characterization and hydrolysis studies of Al-Bi-Graphene-CNT composites synthesized by mechanical milling for enhanced hydrogen generation rate and yield.

From 'Trash to Treasure' - Utilization of Electronic Waste as precursors in Advanced Technologies

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The concept of 'Waste-to-Wealth' is always of great interest for various reasons, including the effective utilization of a large amount of electronic waste or e-waste by recycling valuable materials through sustainable means and thus protecting the environment. In this work, we demonstrate an easily scalable green route for beneficiation and practical usage of constituent materials from the e-waste using cryo-temperature milling. The components obtained through the cryomilling were metallic nanoparticles as well as polymeric residue. The obtained metallic nanoparticles were then used for the selective electrochemical reduction of CO_2 into different gaseous products, resulting in the evolution of CH_4, H_2, and CO as major gaseous products at neutral pH and CO as the major product at basic pH. The polymeric component, on the other hand, was used as a precursor to synthesize graphene *via* pulsed laser ablation in de-ionized water. The

proposed synthesis route demonstrated great promise for producing high-quality graphene. According to XPS, the sp^2 hybrid state is the dominant chemical state of carbon in graphene. TEM and AFM analysis reveal that graphene has ≤ 4 layers with a high degree of crystallinity. Raman spectroscopy was used to analyse and compare the quality of the synthesized graphene to that of commercial graphene. The results show that the synthesized graphene has high quality that is comparable to commercial graphene. Systematic modelling yielded the optimal laser parameters (laser fluence of 20 J/cm^2 with ablation time of 600 sec) for high-quality graphene and a maximum yield of 40.2%. The high-quality synthesized graphene was further used to create highly conductive electronic contacts. In a nutshell, the current approach can provide a useful means of extracting major components from e-waste, which can then be used to produce green energy and valuable materials such as graphene in an environmentally friendly manner, making the process sustainable.

Hydrogen Generation by Hydrolysis of Aluminium Alloys and Composites: A Short Review

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Hydrogen offers an alternative energy source to current fossil fuels, with research being focused on developing sustainable and economical methods to generate hydrogen. Hydrolysis of aluminium alloys and composites shows a promising avenue for on-demand and eco-friendly hydrogen generation. Nevertheless, the aluminium-water reaction is hindered by the inert oxide layer and prevents hydrogen generation, which can be overcome by utilisation of additives, tuning reaction solution etc., to hinder or remove the oxide layer. The present review is an overview of hydrogen generation by hydrolysis of aluminium alloys and composites.

Environmental Viewpoint of SiC Production

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The worldwide silicon carbide market size was estimated at USD 2.52 billion in the year 2019 and is expected to rise with a compounded annual growth rate of almost 16.1% from 2020 to 2027. The developing steel industry is expected to drive this development as silicon carbide (SiC) is utilized as a deoxidizing agent in the steel production and is an important crude material in the refractory production. With increase in production, there will be an increase in both direct and indirect emissions if the process by which we manufacture SiC is not revamped. The process has been optimised at laboratory scale with sustainable efforts by a research group led by Prof. Gupta at IISc, Bangalore. Emission factor was estimated and subsequently carbon equivalents of the optimized process were calculated. The standard emission factors of industry scale plant from emission factor database (EFDB) Intergovernmental Panel on Climate Change (IPCC 2006) were collected and carbon equivalent was calculated. Also, emissions were estimated using input charge data provided by Carborundum Universal Limited (CUMI). Comparison of CO_2 equivalents showed that the optimized experiment leaves much lesser carbon footprint into the environment than industry scale process.

Investigation of EAF Slag under Various Cooling Environment and its Leaching Behavior

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Recycling of solid waste of a steel plant, mainly steelmaking slag, is a big challenge nowadays. Although several techniques have been evolved to recycle the same and extract the valuable

products, as far as steel making slag is concerned, no such techniques are there which can solve the issue to nullify it.
Steelmaking slag from different reactors like BOF, EAF, etc., usually finds its way for land filling which can affect the environment badly along with the monetary losses which are incurred during their handling and transportation. In present scenario, India is the second largest crude steel producer and a major share comes from DRI (direct reduced iron) – EAF route. The slag from EAF steel making usually consist of Fe_2O_3/FeO of 18-30%, CaO of 23-48%, SiO_2 of 2-6%, MgO of 4-17% and Al_2O_3 of 2-15%. This composition usually varies with respect to raw material used. In this study, the EAF slag is heated to molten form followed by cooling it in different medium with respect to their quenching capability. For the present investigation, the slag has been cooled in open atmosphere which is a slow cooling process and for rapid cooling water quenching has been used. The results from rapid cooling confirm enhancement of β-phase of C_2S also known as belite phase, which is mainly responsible for giving slow hydration properties and contributes to higher strength to the material. The study of the leaching effect of elements present in slag is also performed to understand the surrounding interaction before use of the same for construction application.

Keywords: EAF slag, Recycling, Cooling Technique, Characterization.

Tin Recovery from Electro-tinplating Sludge

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Globally, tinplate is produced by the electrolysis process. Out of all tinplating processes, FERROSTAN process is the most popular and widely used. The electrolyte (tinplating solution) used in this process has stannous ions (divalent ionic state) in acid based electrolyte. Due to oxidation in the process, the stannous ions (in divalent ionic stage) get converted to stannic ions (quadrivalent ionic state), which leads to formation of tin sludge.
The loss of these soluble stannous ions from the electrolyte in stannic form increases the consumption of tin anodes which leads to higher operating costs for plating process. The tin sludge

is not only a commercial loss but also a concern as it is a natural resource which has its issues around mining and available reserves. Tin is a high cost metal and steep increase in price of tin has been observed over past few years. As raw material, tin comprises approx. 50 – 60% of total process cost of tinplating lines. It is thereby essential to think of new ideas to reduce tin loss and reuse tin by recovering it from process waste.

The objective of this project is to recover metallic tin from tinplating sludge generated from the tinning process. Dry sludge is being leached and electrolyzed to get pure metallic tin. Tin electroplating from acid (phenol sulphonic acid popularly known as PSA) based electrolyte produces sludge containing approximately 74% tin. This dry sludge is being fused and blended with NaOH and tin foils are collected after electrolysis from cathode. Chemical analysis of the metallic tin confirms the presence of greater than 99% pure tin along with very small quantity of Pb, Fe and Sb. The recovered tin conforms to the food grade tin quality requirements and can be reused in tinplating process.

Utilization of Wastes (Industrial & Agricultural) as Reinforcement in Low Density Metal Matrix (Al, Mg) for Composite Development: A Green Approach for Waste Engineering, Mineral reclamation and Environmental Sustainability

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With rise in global population there is a surge in agricultural and industrial activities to feed the ever incremental demand of mankind. Rise in agricultural and industrial activity automatically leads to some waste generation at site known as agricultural wastes and industrial wastes respectively. Disposal of such waste is a challenge since dumping of wastes leads to landfill and land stress, while incineration of agricultural wastes lead to smoke, particulate matters, volatile organic matters, ash, etc. which are an alarming concern for individual health and environment. Disposal of industrial wastes lead to change in soil chemistry hence affecting agricultural activities while disposal to water bodies causes change in aquatic environmental leading to complex situations like diseases, water stress, change in chemistry of soil and others. To reduce such burden, researchers in last two decades have found a logical solution to reutilize both agricultural and industrial wastes for engineering application depending on the chemistry of waste. Composite fabrication is one important area where agricultural and industrial wastes are on focus especially for light weight durable structural components for possible versatile applications in automobile sector, energy sector and aerospace engineering. Aluminium and magnesium are used widely as material for light weight engineering hence composites based on addition of agricultural and industrial wastes having silica, alumina and other oxides as constituents which act as dispersing agent for improvement of mechanical properties, abrasion resistance and structural integrity. In the present article, a brief glimpse on utilization of both agricultural and industrial wastes for preparing composites based on light weight metal (Al and Mg) is highlighted.

Keywords: Agricultural wastes, Industrial wastes, composites, light weight metal matrix.

Use of LD Slag as Blanketing Material and Ballast Material in Railway Tracks as Replacement of Natural Aggregate

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Ever increasing demand of natural aggregates for construction and rampant reclamation of natural resources has posed major sustainability challenges. To overcome this challenge, different recycled aggregates are being used in construction as a replacement to natural aggregates. In this study, the suitability of LD slag as an alternate material in construction of railway tracks has been explored.

Several possible design mixes were prepared from the mixture of fine LD slag (0-6) mm, weathered coarse LD slag (10-20) mm and fine crusher dust to satisfy the properties requirement as per Research Design and Standards Organization (RDSO) of Indian Railways for blanketing material. This design mixes are tested for several parameters such as gradation, free lime, Los Angeles abrasion test, volume expansion, uniformity coefficient (Cc) and coefficient of gradation (Cu) as per standard. It is found that the design mix composed of 55-60 % LD slag (0-6 mm), 25-30 % of weathered LD slag (10-20 mm) and 15-20 % of crusher dust is the best possible alternate blanketing material satisfying all the requirements as per standard.

Ballast is the selected crushed granular material placed as the top layer of the sub-structure in which the railway track sleepers are embedded. LD slag is characterized in terms of several physical and chemical parameters and its tufa formation ability as per the requirement of RDSO standard for ballast materials. LD slag considering the gradation requirement and other physical and chemical properties requirement of ballast material as per RDSO standard coarse LD slag (40-

65 mm) was found suitable to be used as ballast material. The chances of tufa formation which is a major concern for ballast material is found to be very low in case of LD slag.

Utilization of Biomass derived Charcoal as an Alternative Fuel in Ironmaking

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At present, fossil-based fuel is being widely used in iron and steelmaking process in a different form. The problem associated with the fossil fuel is the emission of greenhouse gases. Charcoal derived from sustainably grown biomass is a possible substitute for fossil based solid fuels such as coal and coke and is a possible way to reduce the net CO_2 emissions for metallurgical smelting operations. Raw biomass is unsuitable for these applications as it contains high moisture and volatile matter, therefore it has to be converted into char (charcoal) through a pyrolysis process before use. In Tata Steel R&D, we have developed a pyrolysis process after optimizing the process variable on charcoal formation and yield during pyrolysis. The effect of heating rate, heating temperature and particle size on the yield of charcoal from mixed wood biomass was quantified in a series of pyrolysis experiments using a tube furnace. The experiments were conducted in the temperature range of 350 to 500 °C with a heating rate of 2-10 °C/min. The charcoal yield was found to be higher at lower heating rate with high residence time. The results indicate that low temperature reactions of charcoal formation are favoured by low heating rates whereas lower heating rates are also associated with increased retention of pyrolysis vapours in the biomass which result in increased production of secondary charcoal and increased charcoal yield.

Keywords: Biomass, Charcoal, Pyrolysis, CO_2 emission.

Effect of Paraffin Wax Particle Size on the Thermal Energy Storage Behaviour of Paraffin Wax-Water Suspensions

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A theoretical study has been carried out to estimate the thermal energy storage characteristics of the phase change material (PCM)-water suspensions (PCM nanofluids). The thermal energy absorbed by the phase change nanofluids from the adjacent heat source has been estimated using a meso-continuum model. Incorporation of phase change material (PCM) to the nanofluids either as a nanoparticle or as a base fluid or as an additive will bring a new form of thermal fluids (PCM nanofluids), which has been studied. A combined beneficial effect of nanofluids and PCM properties makes these PCM nanofluids applicable in both heat transfer and latent heat storage applications. This study provides a review of research in the field of adding nanoparticles to the PCMs, adding nano-PCM particles and combination of nanoparticles and PCM particles to the conventional fluids and numerical studies on their thermal performance. This review also provides information on synthesis of nano-sized encapsulated PCM particles.

Keywords: Nanofluids, Phase change materials, Thermal conductivity enhancement, Latent heat storage.

Advances in Material Science & Technology

KEYNOTE LECTURES

An Introduction to the Vast Virtual World of Additive Manufacturing

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Additive manufacturing (AM) allows the printing of unique metallic parts from digital drawings that cannot be achieved in any other way [1]. However, the selection of alloys, process variants, and variables results in an exceptional diversity of microstructures, properties, and defects. Optimizing the structure and properties of components by trial and error is not a viable option because of the large number of variables involved and the high cost of feedstocks and machines. Solutions to many problems [2] of additive manufacturing are available in the virtual world of mechanistic modelling and machine learning [3]. This presentation seeks to introduce examples of how these tools can be applied to additive manufacturing to solve important problems. Physics-based models of AM, when adequately validated, can provide unmatched insight into the evolution of solidification structure, microstructure, common defects, and printability [4]. Since AM is relatively new, mechanistic understandings of various aspects of AM are still emerging. In these situations, machine learning algorithms aided by data enable the printing of high-quality parts. The application of these powerful digital tools to solve important problems in additive manufacturing does not require any expensive hardware. As a result, the solutions can be contributed by anyone from any region of the world, thus reducing financial inequities in who can learn and contribute. Most importantly, the virtual world has the potential to significantly accelerate progress in metal printing.

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Present and Future Trends of Composites Research and Product in India

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For the last two decades, the increasing demand for lightweight, high-performance materials are being satisfied by fiber-reinforced polymer (FRP) composite material. FRP composites play a vital role in the market and attract various aerospace, space, automotive, structural, chemical, oil, and exploration industries. FRP composites show superior properties (strength to weight ratio, durability, high stiffness, lightweight, corrosion resistance, and excellent fatigue properties) than conventional materials such as steel and aluminium. On the contrary, FRP composites usually fail catastrophically without any significant warning. Therefore, material selection and adequate design are required to enhance the material properties to exhibit a safe, progressive failure process and meet global demand. With advancements in FRP composites, researchers have developed new approaches to improve mechanical properties by incorporating different nano phased materials through CNT alignment in fibrous polymeric composites, matrix modification and/or fiber decoration techniques. On the other hand, Fiber-metal laminates (FMLs) are also gained huge demand in structural industries. FMLs are combination of metals and fiber reinforced polymer composite materials which are adhesively bonded together alternatively. The intention of combining these two different materials is the compensation for their inherent weaknesses. Furthermore, real-time case studies highlighting the durability and applicability of FRP composites in various sectors are incorporated.

Corrosion and its Implications to Industry

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Materials degradation in the form of corrosion is one of major causes for industrial breakdowns, which adversely affect the productivity. Hence it is also associated with great bit of cost for repair, replacement of parts and at times, complete overhauling of entire structures. Corrosion could also induce serious life-threatening accidents as well as immense environmental damage. There have been several such accidents, like Bhopal Gas Tragedy in 1984 (India), collapse of Silver Bridge in 1967 (US), Prudhoe Bay oil spill (US), The Flixborough explosion in 1974 (UK), Sinking of the Erika, the oil carrier ship in 1999 (France), corrosion hole in Davis Basse nuclear plant in 2002 (US), Swimming pool roof collapse in 1985 (Switzerland), etc. Moreover, corrosion affect almost all the industries, such as construction, bridges, oil refineries, chemical plants, ferrous as well as non-ferrous metal production, road, water and air transports, electronics, etc.

Interestingly, corrosion is a natural process and hence it cannot be stopped. At times, high degree of corrosion is also inevitable. Therefore, looking at the severity of corrosion, efforts are being constantly made only to reduce its effect. Some of the well-known methods of corrosion protection of industrial components and structures are in the form of coating, choice of better corrosion resistant materials, change in environments or removal of corrosives, introduction of inhibitors, cathodic or anodic protection and finally, better design of components. Some of the recent trends in corrosion protection are in the form of better coatings, which would have both barrier as well as sacrificial effects, like amorphous and nanocrystalline coating on steel substrate, hydrophobic coatings, self-healing paints, electro-deposited hybrid Zn coatings for protecting steels, use of green inhibitors, use of mixed metal anodes for cathodic protection, micro-texturing of the surface, etc. It is also highly challenging to decide the suitable method of corrosion protection. Therefore, it necessitates constant monitoring, assessment of damage on regular basis, timely decision making to avoid untoward accident, corrosion audit, policy making and finally, raising awareness.

Some of the countries, like Japan, South Korea, Australia, America, etc., have progressed far in the direction of corrosion control and protection of Industrial components and structures. Government level of corrosion audit and support also drives persistent research and development as well as evolution of new technologies towards corrosion protection. Though the corrosion awareness among the industries is gradually improving in India, it is still slow paced. Education in corrosion field in major academic Institutes in India is also not very focussed. One has to realise that to cater to the analysis of corrosion issues and finally devising suitable protection, serious reforms are to be made for knowledge building among the students both in Industry as well as in Academia. And to make it happen, Government needs to come forward by taking necessary steps at a faster pace. After all, corrosion damage in India involves ~ Rs. 6 lakh crore or ~ 4.5 % of Indian GDP!

Emergence of Resorbable Magnesium Based Implant: Road ahead for India

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Orthopaedic fixation is an important surgical procedure globally. For bone cracks to fracture originating from accidents, sports and other miscellaneous reasons, implants made of steels or titanium alloys are used. Once the bone is healed, these implants are removed through a second surgical procedure often called as revision surgery to avoid long term cytotoxic effects and patient discomfort. Revision surgery doubles the medical cost, doctor's time and patient trauma. To circumvent these issues, magnesium-based materials are researched as magnesium-based implants can be resorbed by the body thereby avoiding the revision surgery and caveats associated with it. Magnesium is a nutritional element in nature and our body needs it as a supplement for performing multiple physiological functions. Carefully designed magnesium alloys can serve the need of temporary implants and any excess magnesium that is created in the body due to dissolution of implants post bone recovery can be excreted through urine naturally. Further, magnesium has density, strength and elastic modulus closest to bone making it a perfect implant material. The challenge of using magnesium-based implant is to control its degradation rate so that it matches closely with bone healing. India being one of the most populous country in the world with a huge market size is a perfect place for industry creation to develop and fabricate such implants. Such an initiative can be very fruitful from investor, user, doctors and industrial growth perspectives.

Excitements and Challenges in High Entropy Alloy Research

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HEAs are a new class of multi-component equiatomic (or near equiatomic) alloys, which form simple solid solutions due to their high configurational entropy. Despite the excitement that the field has generated, and the large number of studies being carried out by many groups, there are many challenges in this field both in terms of fundamental understanding and processing. It is important to note that all multi-component equiatomic alloys do not lead to the formation of single-phase solid solution in several cases. Some of the HEAs have shown the formation of intermetallic phases and in some cases phase separation of certain elements with high positive enthalpy of mixing with other elements has been observed. Prediction of the phase formation in HEAs is a major challenge in this field. Understanding the stability of the phases is also a major challenge due to possible sluggish diffusivity in these alloys making it difficult to understand whether the phases obtained are thermodynamically stable or kinetically stabilised. Processing of the alloys in large quantities in various forms for useful applications also remains a major challenge. The present paper brings out some of these issues based on the ongoing work in the research group of the speaker.

Joining of Advanced Materials for Defense Applications-Techniques and Challenges

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Joining of materials is indeed an important aspect for both designers and fabricators. Ideally, it is preferred to manufacture a product without any joints, since joints are source of weakness. The reasons for joining are functional, structural aspects and cost reduction. No other technique is as widely used as welding to join materials efficiently and add value to their products. Many applications of conventional and modern engineering materials are limited by their ability to be joined. Innovative development in welding technologies and processes are required to achieve with greater productivity and enhanced quality of components manufactured by the welding industry. Metal joining processes consisting of fusion welding, solid state welding, brazing and soldering are employed to join many of materials in similar and dissimilar combinations. The problems in the joining are related to metallurgical characteristics influenced by the welding processes. In dissimilar combination, metallurgical compatibility is the main issue. Weld zone grain refinement with inoculants and advanced welding techniques to improve weld zone properties also form a part of this lecture. Effect of heat input and welding processes on ballistic behaviour of heat affected zone armor steel welds, improvement in ballistic properties of soft welds with hard surfacing and selection of filler metal for resistance to delayed cracking in armor steel welds are outlined. Effect of electron beam oscillation patterns on the structure and properties of titanium, Inconel-718 and aluminum alloys are discussed. Joining aspects of incompatible materials such as aluminium to titanium alloys, titanium to nickel, titanium to stainless steel and aluminium to stainless using fusion and solid state welding processes are also described. In fusion welding, the issues are solidification related segregation and consequent influence on solid state metallurgical transformations, porosity, solidification cracking etc. Hydrogen related delayed cracking is one of the major problems encountered by the majority of high strength steels and other materials to a lesser degree. Solid-state joining processes eliminate the solidification related metallurgical and quality problems frequently encountered during conventional fusion welding. The science of joining by the friction stir welding route was established in variety of materials of interest to industrial applications, and an elaborate understanding about the influence of material, tool and process parameters on achieving successful joints through extensive experiments are also outlined in this lecture.

Materials for Defence Systems

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Materials technology is a truly cross-cutting technology that underpins almost all defence systems and requirements. Ships, submarines, aircraft, military vehicles, radars, sonars and missiles all need materials that enable significant improvement in their performance. The sheer diversity and multitude of structural and functional materials which are used in defence systems makes it impossible to discuss all of them in this talk. Instead this talk will focus on the applications of steels and aluminium alloys whose usage is by far the highest in defence systems. The talk will also bring out the challenges faced in materials development for defence and the need to accelerate the materials development process to meet the emerging defence system development cycle.

ICME Workflows and the Role of Microstructure Simulations

Gandham Phanikumar

In the recent few years, the Integrated Computational Materials Engineering (ICME) approach has gained importance across the globe. Several conferences, workshops and reports have contributed to the popularity of this approach. The maturity level of the software components, the high performance computational resources available and the emergence of digital platforms for integration have contributed to the growth of ICME as an approach to lower the cycle time for development of engineered products. Workflows are articulations of how different tools communicate relevant information with each other to arrive at a target outcome. In the process of integrating experimental validations into the ICME workflows, the most challenging aspect that one comes across is that of microstructure simulations. Multiphase and multi-component alloys pose significant challenge on the material data availability as well as intense computational requirements. In this talk, using examples from solidification, welding, forging and additive manufacturing, I shall illustrate the workflows for the ICME approach that involve these processes. Recent advances in microstructure simulation will be presented to discuss how the challenges posed on this aspect are being addressed currently. Maps from physical space (x,y,z) to parametric space (of thermal gradient, cooling rate, growth rate etc.,) will be illustrated to guide the microstructure simulations for integration into ICME workflows.

ORAL PRESENTATIONS

Constitutive Modelling of Grain Boundary Strengthening Characteristics in Complex Concentrated Alloys

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Complex concentrated alloys, owing to their inherently high friction stress and solid solution strengthening, have proved quite potent as futuristic engineering materials. The past few decades have seen a tremendous surge in studies related to thermomechanical treatments and microstructural modulation of this class of alloys. However, the approach has been mostly a trial and error based methodology to obtain optimized combinations of strength and ductility. Grain boundary strengthening being a major contributor to the yield strength of the system, has been modeled into a suitable microstructure entropy parameter. This takes into account not only the Hall-Petch parameter in the form of average grain size, but also the grain size distribution, rendering the YS prediction for a given microstructure to be more accurate and enhancing the predictive capability before performing mechanical tests and experimentation. A similar approach can be adopted for modeling defect densities to compute other strengthening contributors, which can give a vivid picture of the overall mechanical properties of an alloy. The microstructure entropy parameter has been utilized to predict the Yield strength of ternary equiatomic complex concentrated alloy of FeMnNi. Microstructural characterization has been performed to obtain stochastic data related to grain size distribution. A comparative analysis with the Hall-Petch parameter shows a better correspondence with the experimental results, corroborating the accuracy of the described model.

Polarization Light Microscopy for Characterizing Micro-Texture in Unidirectionally Rolled Ti64 Plate – Structure Property Correlations

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Conventional thermomechanical processing of Ti6Al4V alloy used to manufacture components often results in regions with a strong crystallographic texture. These micro-texture regions (MTR) can span several millimeters in multiple dimensions, especially in semi-finished products such as rolled plates. MTR's can retain a strong basal or prismatic crystallographic texture and the presence of MTR's can significantly affect the mechanical behavior of the alloy, in cyclic loading (fatigue) and hold time (creep). Characterizing the MTR's is non trivial. Electron back scattered diffraction (EBSD) is one of the techniques that is able to detect the location and morphology of the MTR's. However, EBSD is time consuming and is restricted to relatively smaller regions in the sample. In order to establish the mechanical property correlation with MTR's shape and size, this study relates to a detailed mapping of the MTR's using polarized light microscopy (PLM), using the light optical microscope. A detailed mapping of the MTR's has been carried out using PLM with a correlation to the EBSD images. These have been used to understand the room temperature and high temperature (200 °C) mechanical behavior.

Sorption Studies of Cerium as Surrogate Material for Plutonium using Nitrogen Doped Graphene Nanowalls

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Environmentally and strategically, there is a growing demand for improving the efficiency of plutonium and fission products recovery from low (ppm or ppb) concentrate effluents in the back end of nuclear fuel cycle. Several materials with varying sorption efficiency have been suggested [1,2]. However, graphene nano-walls (GNWs) exhibit several unique properties such as non-agglomerating and self-standing nature with exceptionally high surface area (>2% of monolayer graphene), chemical and thermal inertness and ease of large-scale synthesis on a variety of substrates. Nitrogen doping can make the graphene nano-walls (N-GNWs), a superior sorbent owing to high structural defect density, presence of hydrogen, nitrogen and oxygen containing functional groups and local p-type, n-type and polar regions [3,4]. Hence, sorption studies are conducted on N-GNWs using cerium, a major fission product and a surrogate element to plutonium. The nano-sorbent GNWs are deposited on carbon paper and nitrogen doped using plasma enhanced CVD technique. Basic characterisation using SEM (Fig.1) and Raman spectroscopy has been carried out. The sorption experiments were conducted by batch adsorption technique at ambient temperature and at varying pH conditions over 1 ppm to 10 ppm solution of certified reference material (CRM) cerium. Inductively Coupled Plasma Optical Emission Spectroscopic study shows a sorption efficiency of 92 ± 2 % for Ce in 1 ppm solution at pH~7(Fig.2). It is theoretically deduced from speciation modelling that Ce co-exists preferentially as non-hydrolysed and hydrolysed cationic species at pH above 7. The increased sorption efficiency at pH above 7 is attributed to surface complexation of the hydroxy species of cerium with the active centres on the surface of the graphene nano-walls.

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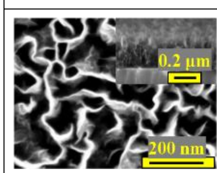
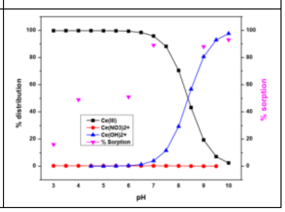
Fig. 1 SEM image of GNWs	Fig. 2 variation of percentage Sorption with pH
	

Effect of Microstructural Constituents on Yield Strength in Ultrafine-grained Ni-Fe alloy

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Ultrafine-grained (UFG) pure Ni and Ni-5%Fe were fabricated through the electrodeposition method. Room temperature yield strength (0.2% offset) of both the materials, pure nickel and Ni-5%Fe, with four different grain sizes in each case, were determined experimentally. Microstructural characterization of grain size distributions and evaluation of dislocation densities were done using electron backscattered diffraction (EBSD) and convolution multiple whole profile (CMWP) methods. Contribution of different strengthening mechanisms operative in material systems such as Peierls–Nabarro stress (σ_0), Hall-Petch strengthening (σ_{gb}), solid solution strengthening (σ_{ss}), dislocation strengthening (σ_d) to overall yield strength were calculated individually. In the case of Pure nickel, linear additivity of strengthening mechanisms were found to predict the yield strength (σ_{ys}) correctly, whereas in the case of Ni-5%Fe alloy, linear additivity did not hold good and the experimental results were found to follow the relation: $\sigma_{ys} = \sigma_0 + (\sigma_{ss}^{1.2} + \sigma_d^{1.2} + \sigma_{gb}^{1.2})^{1/1.2}$

Keywords: UFG Ni-Fe alloy, EBSD, CMWP, Yield Strength

Effect of Process Parameters on Evolution of CSL Boundaries in 316LN SS for Enhancing High Temperature Mechanical Properties

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Grain Boundary Engineering (GBE) is an emerging methodology for improving the material properties of engineering applications. It is observed to be most appropriate method for enhancing

high temperature tensile, creep and fatigue properties of low stacking fault energy materials such as present 316LN SS which is a candidate structural material used for fabricating components for fast breeder reactors. However, GBE primarily depends on tailoring the thermo-mechanical treatment parameters to increase the volume fraction of coincident site lattice (CSL) boundaries. In this study, the evolution of CSL boundaries in 316LN SS with varying degree of prior cold work (PCW) and annealing temperatures has been investigated. Further, microstructural investigation of GBE processed 316LN SS exhibited a bimodular grain distribution, with considerable volume fractions of twin boundaries. It has been observed that GBE processed samples comprising of 20 and 15% PCW followed by annealing at 900 °C, 950 °C and 1000 °C for 0.5 hrs respectively produced microstructures consisting of a higher volume fraction of CSL boundaries. In contrast, at intermittent PCW range, lower CSL fraction after annealing at three temperatures has been observed and importantly this PCW range was relatively wider after annealing at 950 °C. The fraction of prolific twining increased with the degree of PCW, irrespective of the annealing temperature. The underlying mechanisms responsible for lowering the volume fractions of CSL boundaries in the intermediate PCW range has been investigated.

Simulation Guided Grain Refinement Studies on As-Cast Multicomponent Alloy

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The development of multicomponent alloys with good strength and ductility combinations is challenging. Several reports show the application of thermo-mechanical processing to enhance the properties, which requires further energy utilization. The application of grain refiners can be utilized to modify the properties in the cast condition. In the current study, a multicomponent CoCrFeMn alloy was selected. The effect of the addition of various trace elements is studied using thermodynamic simulation using Thermo-Calc. The simulation studies identified the maximum amount of trace elements addition without any new phase formation. A master alloy was made and characterized. Trace elements are added to the master alloy, and the effect on grain size was established. The detailed SEM and optical microscopy characterization were carried out to establish the effect of each trace element addition. The mechanical properties are evaluated and show remarkable variation with the base material. The studies confirm that simulation-guided

experiments will accelerate alloy development.

Experimental Determination of Quaternary Isotherm of Fe-Ni-Co-Cu by Diffusion Couple Technique

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Predicting phase equilibria in multicomponent alloys is of utmost importance to understand the thermodynamics of the system. Nevertheless the efforts to compute the phase equilibria in quaternary or higher order alloy systems are lacking in the literature. Most of the methods depend on empirical criteria for obtaining phase diagram based on the optimized thermodynamic parameters. Extrapolation from binary and ternary data to multicomponent systems makes these approaches unreliable. Experimental determination of phase diagram using conventional process is more tedious for higher order systems as they require abundant amount of alloys and their characterization. This effort can be significantly minimized by diffusion couple technique. In this technique two solid materials are brought in contact with each other and heated at high temperature (below solidus temperature) where inter-diffusion of constituent elements will occur. At that temperature, concentration profiles and diffusion structure developed in the interdiffusion zone represent the phase equilibrium over developed composition range. In the earlier study, experimental determination of quaternary isotherm for Fe-Ni-Co-Cu system at 950 ºC was carried out in the FCC miscibility gap region. In the present work the remaining part of the quaternary isotherm i.e., the BCC+FCC region is constructed at 950 ºC using diffusion couple technique. Diffusion couples are prepared such that one of the terminal alloys contains BCC phase and the other comprises FCC phase. Interfaces developed in the interdiffusion zones are analyzed to find the equilibrium composition of the two phases.

Low Temperature Densification of Zrb_2 through Spark Plasma Sintering using Milled Zr+B as Sintering Aid

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Zirconium Diboride (ZrB_2) is one of the ultra-high temperature ceramics which can be used in extreme environments such as thermal protection systems of hypersonic vehicles. ZrB_2 has strong covalent bonding and low self-diffusion coefficient, which requires high temperatures (>2000 °C) or high pressures for achieving high density by conventional sintering. In the present work ZrB_2 ceramics were densified using reactive spark plasma sintering technique at 1500 °C using ball-milled Zr-B powder mixture as sintering additive. The reaction between Zr and B during sintering is highly exothermic and is expected to help in densification of ZrB_2 ceramics. Zr and B powder were taken in 1:2 atomic ratio and milled for 8 h. The milled Zr-B mixture was added (10 and 20 wt. %) to ZrB_2 and milled again for 2 h. Relative densities of 99.3% and 99.5% were achieved for 10 and 20 wt.% addition of milled Zr-B powder. X-Ray analysis showed that presence of ZrO_2 in the samples. The reactively formed ZrB_2 grains during sintering were very fine compared to the ZrB_2 grains formed from the ZrB_2 powder. Among the two compositions, the ZrB_2-20ZrB (milled) sample showed better mechanical properties with elastic modulus, hardness and indentation fracture toughness of 402 GPa, 24.1 GPa and 5.7 ± 0.9 MPa.m$^{0.5}$, respectively. The SEM images of the indentation cracks showed crack bridging and deflection as major toughening mechanisms. This study shows that reactive mixture of Zr-B can be used as a sintering additive for low temperature sintering of ZrB_2.

Phase Stability of a Novel HCP High Entropy Alloy

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High entropy alloys (HEAs) with body-centered cubic (BCC) and face-centered cubic (FCC) structures have received more attention as compared to hexagonal close packed (HCP) based HEAs. This work emphasis on fabrication and phase analysis along temperature of a novel AlCoTiZn high entropy alloy with dual-phase structure up to melting point. Scanning Electron Microscopy (SEM), Atomic Emission Spectrophotometry analysis, Differential Scanning Calorimetry, X-ray diffraction, and hardness measurements were used for characterization of the HEA. Final phase consists of a dual phase structure i.e. HCP and Co-rich BCC. No phase transformation has been witnessed until 500 °C followed by dynamic phase transformation and vaporization of Zn occur around 900 ^{o}C, revealed through thermal stability studies. Bulk sample of mechanically alloyed sample has shown a distinguished hardness of 1005 ± 50 HV, because of the presence of dual phase.

Effect of Si Addition on Phase Evolution and Microstructure in Y_2O_3 Dispersed Tungsten (W) and W-Based Alloys Synthesized via Mechanical Alloying and Consecutive Conventional Sintering

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Oxide dispersion strengthened (ODS) tungsten (W) alloys are progressively used for critical engineering applications like high temperature, fast wall in nuclear reactor and kinetic energy penetrator. Besides their achievements related to high strength and resistance to radiation, ODS W alloys have downsides such as formation of highly volatile WO_3 compound at high temperature due to oxidation. To suppress oxidation of W and W based alloys, various self passivating ODS W alloys are developed by adding silicon which forms a protective oxide layer on the tungsten alloy surface when they come in contact with oxygen and prevents further oxidation. The present research reports the fabrication of nano yttria (0.3 wt. %) dispersed pure W, W-10Ni, W-10Ni-3Co, W-1Si, W-10Ni-1Si, and W-10Ni-3Co-1Si alloys by mechanical alloying (MA) of W, Ni, Co, Y_2O_3, and Si powders for 10 h and consecutive consolidation via conventional sintering under H_2 gas atmosphere at 1500 °C for 2 h. It has been found that the addition of 1 wt. % Si causes a faster reduction in particle size and results in finer and uniform particles. The X-Ray diffraction and transmission electron microscopy analysis reveal the formation of nano-scale WSi_2

intermetallic compound in the W-1Si-0.3Y_2O_3 alloy and it is observed that the Ni and Co addition prevents the formation of the intermetallic compound in the W-Si alloy systems during milling. However, the appearance of SiO_2 oxide phase in W-10Ni-1Si-0.3Y_2O_3 and W-10Ni-3Co-1Si-0.3Y_2O_3 alloys is observed after sintering. The values of crystallite size, relative density, and hardness values are measured for investigated alloys. Sintered densities of 95% and 96% are observed in the case of W-10Ni-1Si-0.3Y_2O_3 and W-10Ni-3Co-1Si-0.3Y_2O_3 alloys respectively. The highest hardness value of 5.4 GPa is achieved in W-1Si-0.3Y_2O_3 alloy with a sintering density of 82.3%. The effect of Ni and Co along with Si in ODS tungsten alloys has been studied and the phase evolution, microstructure, density and hardness of the fabricated alloys have also been investigated.

Impact of Extrinsic and Intrinsic Factors on the Indentation Behavior of a Dual Phase Steel-a Finite Element Modelling Study

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Modelling mechanical response of structural materials while taking into account their microstructure is of immense interest to researchers attempting to engineer the microstructure accordingly. Such models inherently depend on inputs from experimental data. For microstructures with more than one phase like dual-phase or complex phase microstructures, phase specific properties are not readily available in the literature. Nanoindentation is a technique that has been employed to map mechanical properties like hardness across the microstructure. The resolution of such a mapping depends on the distance between the indents all the while avoiding an overlap of the plastic zone of indentation. In this work, we model the dependence of plastic zone size on extrinsic (indenter geometry and radius) and intrinsic (material properties like yield strength) factors using finite element simulations of the indentation. We validate our simulations by comparing model results with experimental data from Berkovich as well as Vickers indentation on a ferrite-martensite (10 vol.%) dual phase steel. Additionally, we create random 3D microstructures with different martensite grain-size distributions, volume fractions and phase-hardness differentials. The hardness, modulus as well stress-strain behaviour of ferrite and martensite is obtained for such microstructures to show the effect of microstructural variables on composite as well as phase-specific mechanical properties. Lastly, the partitioning of local mechanical properties like equivalent plastic strain and von Mises stress beneath the indenter is obtained. Such data is then used to understand the behavior of individual phases during

deformation under a triaxial stress state.

Keywords: Nanoindentation, plastic zone size, dual phase steel

Microstructure and Properties of Cost-Effective $AlCrFe_2Ni_2$ High Entropy Alloy Processed by Severe Cold-Rolling and Annealing

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High entropy alloys (HEAs) have emerged as a novel class of structural materials owing to their intriguing microstructure and enhanced mechanical properties. Nevertheless, most of the HEAs are featured by the presence of costly alloying elements (such as cobalt), which hinder the engineering applications of these materials. Therefore, the design and development of cost-effective HEAs without compromising the mechanical properties are pressing needs for achieving a breakthrough in that direction.
In the present work, we investigated the microstructure and properties of cobalt-free cost-effective $AlCrFe_2Ni_2$ high entropy alloy (HEA) processed by severe cold-rolling and annealing. The as-cast material showed a heterogeneous microstructure featured by coarse-lamellar regions along with fine intertwined regions. The coarse regions consisted predominantly of FCC and B2 phases, while the fine intertwined regions showed BCC/B2 phases due to spinodal decomposition. Severe cold-rolling resulted in remarkable microstructural features such as bending of lamellae, kinks, folds, local shearing, and finally deformation-induced nanocrystallization. Annealing at different temperatures resulted in an ultrafine microduplex structure with significant resistance to grain growth as well as a remarkable balance in strength and ductility. The present results indicate that the microstructure and properties of cost-effective $AlCrFe_2Ni_2$ can be successfully tailored for advanced structural applications.

Keywords: high entropy alloy, cold-rolling, annealing, nanostructure, mechanical properties.

Statistical Analysis on Single Versus Successive Pop-Ins in Nanoindentation Tests of Zr-Based Bulk Metallic Glass

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3-parameter bimodal Weibull distribution best captures the stochastic nature of incipient plasticity in bulk metallic glasses (BMGs). The present study studies successive pop-in events in the load, P, vs. displacement, h, curve that describe further evolution of plasticity in BMGs. Statistical tools like maximum likelihood estimates and Akaike information criterion are extracted from indentation data for the first 3 pop-ins in the P-h curves. It was observed that while the 2[nd] and 3[rd] pop-in load distribution is also modelled by the 3-parameter Weibull distribution, the parameters undergo a significant change from that observed for the 1[st] pop-in load distribution. The effect of structural state and the size of the indenter were also considered to discuss the formation of subsequent shear bands in BMGs.

Phase Evolution of AlCoCrFeNi High Entropy Alloy

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AlCoCrFeNi high entropy alloy (HEA) is one of the most studied HEA, owing to a better combination of strength and ductility than other Al-based HEAs. AlCoCrFeNi majorly crystallizes as a single-phase BCC alloy, but many literatures have also shown the presence of sigma and FCC phases in the alloy. A detailed understanding of phases and phase transformation temperatures are yet to be clearly demarcated; which is major motivation behind this work. In the present study, a pseudo binary phase diagram of AlCoCrFeNi has been developed using the Thermo-Calc - TCHEA3 database. A total of 20 pseudo-binary phase diagrams were developed to study all possible compositions and the in-detail effect of individual elements on phase stability and evolution independently. To validate the simulated phase diagrams, a separate comprehensive

phase evolution of mechanically alloyed AlCoCrFeNi was recorded through in-situ XRD and DSC between 100 °C–125 °C. The obtained simulated and experimental results match closely up to a great extent, and show similar phase evolution, which can also be expanded for non-equiatomic compositions. Simulated results show AlCoCrFeNi stabilizes as a BCC phase between 0 °C-560 °C, and sigma phase appeared along with the BCC phase between 550 °C-1000 °C. Above 1000°C, the sigma phase destabilizes and the alloy transforms into the dual-phase of BCC and FCC between 1000 °C-1100 °C. Above 1100 °C alloy transforms back into the single-phase BCC and shows the average melting point of 1410°C. Fe, Cr, and Ni seem to favour the sigma phase formation below 1000 °C. The temperature regions for various phases, dependent on composition have been mapped; which can be helpful in designing alloy for desired applications.

A Novel Method to Create a Gradient Microstructure in OFHC Copper

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In the past few years, the gradient microstructures, particularly grain size gradients are in focus because of their potential to address the strength-ductility trade-off. This gradient material with nano or ultrafine grains on the surface and the coarser grains inside the material consequently improve the mechanical properties, i.e. tensile strength and fatigue properties. However, conventional methods to produce gradient microstructures are batch type, limiting their potential applications in the industries. Therefore, we need a continuous method to produce gradient microstructures. In our present work, the gradient microstructure based on the grain size was produced by rolling of a trapezoidal groove shaped plate of oxygen free high conductivity pure copper (OFHC) at room temperature. A trapezoidal groove (TG) was prepared on top and bottom of the plate that gives a 6 mm minimum thickness at the center of a 10 mm thick plate. The sample was rolled for a von Mises strain of 2.19 at the step of 0.12 von Mises strain. Due to TG, the center region of the sample only gets a von Mises strain of 1.60. As a result, a gradient in strain was developed along TD, which was evaluated using finite elemental analysis. Further, the rolled sample was subjected to short-term annealing at 573 K for 0.5 h. Microstructure analysis shows that the central region consists of coarse grains, and grain size varied along TD from centre to end of the sample. Variation in grain size can be attributed to different rates of recovery and recrystallization in different zones of deformation. As a result of the microstructural changes, the hardness of the material increases from the center to end of the sample along the TD. Improved tensile strength without compromising ductility was observed. Detailed deformation mechanism

and texture evolution along the width of the sample and the effect of the gradient microstructure on tensile behaviour of the sheet specimen will be discussed.

Freestanding High Entropy Alloy Thin Film

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High entropy alloys (HEAs) use previously untapped region of alloy composition field to design alloys. These class of near equimolar, multicomponent alloys offer additional parameters to tailor alloy property such as high entropy, local lattice distortions, sluggish diffusion, and cocktail effect. Recent work on application of high entropy alloy film (HEAF) have shown promising results as high hardness coating, corrosion resistance coating, and diffusion barriers in integrated circuits etc. Cantor alloys (CoCrFeNiMn) are good candidates for such application with their exceptional malleability and damage tolerance due to excellent tensile strengths, ductility, fracture toughness among others.

Various deposition techniques have been used to prepare and study HEAFs however limited work has been reported on fabrication of freestanding thin films of these alloys and their applications. This work presents a simple yet reproducible, physical vapour deposition (PVD) based approach to fabricate HEAFs on different substrates. The technique was used to prepare freestanding amorphous as well as crystalline HEAFs with well controlled microstructure. The effect of various growth parameters on crystallinity, microstructure and compositional uniformity of the film was explored and the results obtained from the scanning electron microscopy and transmission electron microscopy and X-ray diffraction-based techniques will be presented in this work.

Application of Body-Diagonal Diffusion Couple Technique and Square Root Diffusivity Approach to Investigate Interdiffusion Behaviour in Quaternary and Quinary Systems

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Determination of interdiffusion coefficients in quaternary and higher order systems has been absent in the literature because of the lack of a proper experimental techniques. In the present work, application of recently proposed Body-diagonal diffusion couple technique and the Square root diffusivity method for the determination of quaternary and quinary interdiffusion coefficients in Fe-Ni-Co-Cr and Fe-Ni-Co-Cr-Mn systems at 1000 °C will be presented. Existence of the strong diffusional interactions have been observed in terms of interdiffusion coefficients, fluxes and concentration gradients in quaternary Fe-Ni-Co-Cr and quinary Fe-Ni-Co-Cr-Mn systems. Especially strong diffusional interactions between Ni and Mn and those between Co and Mn are noteworthy. Interdiffusion flux of Ni is enhanced up the gradient of Mn whereas that of Co is enhanced down the gradient of Mn. Present work findings suggest that Body-diagonal diffusion couple technique and the square root diffusivity method works well for the determination of quaternary and quinary interdiffusion coefficients until the constraint of constancy of interdiffusion coefficients in the diffusion zone is satisfied.

On Effect of Electron Concentration, Energy Level, and Atomic Mismatch on Quantitative Phase Prediction in High Entropy Alloys (HEAs)

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Dual-phase high entropy alloys have shown superior mechanical properties than their single phase counterpart, such as high strength while retaining significant ductility. The properties of a dual-phase alloys largely depend on the phase fraction of secondary phases. Various combinations of empirical and thermodynamic parameters such as Valence electron concentration (VEC), mixing enthalpy (ΔH_{mix}), atomic size mismatch factor (δ), and mixing entropy (ΔS_{mix}), among others are used to predict the phase stability and crystal structure of high entropy alloys. However, the predictions using these parameters are qualitative in nature. In this work, we propose a novel computational approach to predict the phase fraction in dual-phase high entropy alloy using various measures of electron concentration, energy level, and atomic size mismatch. A new empirical criterion, namely, critical mismatch factor (δ_c), is also proposed. This work also presents the regression analysis of various alloying parameters such as VEC and average d-orbital energy level (Md). It was found that both VEC and Md have similar potency to predict the phase fraction through the approach proposed in this work. The utility of the approach is demonstrated by comparing predictions with available literature data and experimental measurements. The work is particularly important and timely as many attempts are being made to develop high entropy alloy for high-end structural applications.

Phase Stability and Magnetic Properties of $Co_2FeAlMnSi$ HEA

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High entropy alloys contain multiple elements, generally more than 5, with composition varying from 5% to 35% at. The maximized configurational entropy has been shown to impart fascinating structural and functional properties to these alloys. HEAs are being explored for magnetic applications, where lot of research is focused on achieving high magnetic saturation and low coercivity. The present work explores HEAs for spintronic applications i.e Spin transfer torque magneto-resistive random access memories (STT-MRAMs). Heusler alloy $Co_2FeAlMnSi$ is prepared by vacuum arc melting followed by homogenization at 1200 ºC for 48 h. The addition of Mn and Si is done to optimize the reduction in damping parameter and increase in magnetic moment. The phase analysis has been performed using X-ray diffraction and compositional analysis is carried out using Scanning Electron Microscopy (SEM). Thermal stability of alloys has been demonstrated by doing annealing treatments, followed by phase analysis, in a wide temperature range. The magnetization behavior is measured using Vibrating Sample Magnetometer (VSM) and damping parameter is determined using ferromagnetic resonance (FMR).

Segregation of Alloying Elements at Prior Austenite Grain Boundaries in Boron Added Modified 9Cr-1Mo Steel Studied by Atom Probe Tomography

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Ferritic steels are used in thermal power plants and heat transport systems due to their very good thermos physical property, weldability, formability and better high temperature properties below 600 °C compared to stainless steel. Feritic steel evolved over a period of time to cater energy demand[1–3].Weld joints of this steel are susceptible to Type IV cracking[4–6]. Boron addition reported to improve creep strength and Type IV cracking resistance of ferritic steels[7,8]. Boron, carbon and Mo are reported to segregate at the prior austenite grain boundaries in 9Cr steel in as quench condition and proven using 3D APT[9]. Li et al. reported B and Mo segregate at PAGB via a non-equilibrium mechanism[9]. They also reported segregation occurs by B-vacancy complex. Abe et al. reported reconstitution prior austenite grain in the heat affected zone (HAZ) of 9Cr-3W-3Co-V-Nb-N-B steel[7]. It is reasonable to understand boron segregation as it has limited solubility in the iron matrix. Boron commonly replaces carbon from $M_{23}C_6$ precipitate during tempering and creep. $M_{23}C_6$ precipitate mainly forms at the prior austenite grain boundary, packet boundary, block and lath boundaries. The size of this precipitate varies depending on sites of nucleation and it is biggest at the PAGB and lowest at the lath boundaries. It was also reported that boron content in the $M_{23}C_6$ precipitate is more which form at the PAGB than that form at the lath boundaries[10]. This explain why boron segregation was always reported at the PAGB. Segregation of intended elements in any alloy makes their limited use. Therefore, it is essential and obvious to understand the desegregation behaviour of all segregating elements during heat treatment. The objective of present investigation is to understand the influence of segregation behaviour of different alloying elements in boron added modified 9Cr -1Mo (P91B) steel with the help of atom probe tomography.

Microstructure Evolution of AlCoCrFeNi High Entropy Alloy during Electrospark Deposition

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Electrospark deposition (ESD) is a surface modification technique wherein high energy pulsed discharges between electrode and metallic substrate can deposit the melting electrode on to the substrate with a good metallurgical bond and small heat affected zone. AlCoCrFeNi high entropy alloy (HEA) show good hardness and wear resistant and has potential to use as a coating. Present work studies the coating behavior of AlCoCrFeNi HEA on a martensitic stainless steel. The present focus was particularly on microstructure and phase evolution of this alloy during the deposition process. The alloy was prepared through mechanical alloying followed by hot pressing. Sintered alloy was used as a feeding filament for electrospark deposition. The 12-Cr martensitic steel was used as a substrate. A significant variation on the same was observed, compared to the feeding filament (which was a sintered alloy). Phases were characterized through x-ray diffraction whereas phase fraction and morphologies and orientation were characterized through electron backscattered diffraction (EBSD) analysis. Result suggest a variation in hardness values across the coating thickness. Properties anisotropy was also observed depending on test direction (indentation) among top coating surface and its cross-sections. These variations in properties could be attributed to the variation in the microstructures and phases.

Keywords: High-entropy alloys; electrospark deposition; hot pressing, EBSD.

Microstructure, Texture and Hardness Evolution in High Pressure Torsion of $Fe_{40}Mn_{40}Co_{10}Cr_{10}$ High Entropy Alloy

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The concept of high entropy alloys (HEAs) have opened up a very large compositional space for new alloy design. Nano-structuring of HEAs offers the possibility of achieving enhanced mechanical and functional properties. In this work, nano-structured HEA is achieved using high pressure torsion (HPT) route. It was observed that $Fe_{40}Mn_{40}Co_{10}Cr_{10}$ HEA, which is otherwise

believed to be a TWIP HEA showed extensive FCC-to-HCP transformation (TRIP effect) even at relatively lower shear strain. Furthermore, it was observed that extensive non-basal slip was prevalent which was attributed to a c/a ratio < 1.633 in the transformed HCP phase. Extensive non-basal slip left its signature on the texture evolution as well. Hardness was found to be a function of both number of turns of HPT processing as well as distance from the centre of the disc, which is consistent with the varying shear strain.

Keywords: High entropy alloy, Transformation induced plasticity, Non-basal slip, c/a ratio, Nano-structuring

An Improved Method for Prediction of UTS from Small Punch Test

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Small Punch (SP) test is a promising test method for extracting the mechanical properties such as yield strength, ultimate tensile strength and fracture toughness using small size specimens of typically about 0.5 mm in thickness and 8-10 mm in diameter. As the loading configuration and material deformation in SP test is itself different form uniaxial tensile test, the methods for determination of strength and ductility are not straight forward, as in tensile test. Correlation based methodologies have been in vogue for YS and UTS evaluations from SP test which require material specific constants derived through prior experiments. In the light of above, numerous methods and correlations have been proposed by researchers for UTS determination using the maximum load and corresponding displacement. In recent times, a new method based on numerical simulations was proposed by Altstadt et al. for UTS estimation using the load corresponding to a specific displacement in the membrane stretching regime of deformation as a better parameter instead of the maximum load. Authors have examined the veracity of this method through both numerical simulations and experiments and have identified certain shortcomings which will be briefly presented. Further, an improved method for UTS estimation based on the variations of the slope of load-displacement curve of SP test is being proposed. Through finite element simulations and experiments on various steels over a range of strength levels, it is observed that the load and displacement corresponding to the proposed instability point correlates well with UTS when compared with existing methods. The presentation will include the details and results of the proposed method for UTS determination from small punch tests and the comparison of the

correlations obtained with different methods.

Keywords: Small Punch (SP), Ultimate Tensile Strength (UTS), load-displacement curve, correlation.

Computation of Elastic Constants and Generalized Stacking Fault Energy of Pure Metals and Alloys Using First Principal Calculations

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Ab initio approach is popularly used to calculate properties of solids without the need of any empirical or experimental parameters. Two fundamental requirements for efficient computation using this technique are: information about interaction of atoms as described by the fundamental laws of physics, and assumed models and approximations to establish a reasonably accurate correlation. Elastic constants and elastic moduli are the fundamental parameters, which describe the mechanical properties of any material, and enable prediction of deformation behavior under various loading conditions. Elastic constants for single crystals can be computed reliably from first principles bearing good coherency with experimental methods. The case with polycrystals is slightly complex. However, the advantage of employing the supercell concept is that DFT calculations can be performed with a high degree of accuracy, exercising freedom of choice for crystal symmetry, geometry relaxations, spin polarization, etc. In a similar way, defects can be modelled ideally by multiple defect atoms within a matrix of an infinite number of host atoms. Using this, the current work is focused on computation of mechanical parameters for unary, binary and ternary alloy systems, including concentrated alloys like Ni-Co and medium entropy alloys, by exploiting DFT based computational capabilities of Quantum Espresso (QE) and Vienna Ab initio Simulation Package (VASP). Additionally, modelling the planar defects (stacking faults), the Generalized Stacking Fault Energy (GSFE) curves for the investigated systems have been plotted, which reveal the micro-mechanism of deformation, without the need for subjecting the material to destructive mechanical testing. The results obtained by this computational study has also been compared with the trends obtained experimentally, which validates the proposed model.

A Novel Mean Field Dislocation Density Reliant Physical Model to Predict the Creep Behavior of 304HCu Austenitic Stainless Steel

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Physical based creep modelling enables us to understand the life-limiting factors that are required for a safe and economic operation of power plant components. Thus, herein a novel physical approach to address the creep behavior of 304HCu austenitic stainless steel is presented. This approach combines a dislocation density reliant physical model with a continuum damage mechanics (CDM) model. Two different dislocation densities: mobile and forest, and dislocation mean free path are used to describe the substructure in order to model the creep strain. The original Orowan's equation for estimating creep strain rate is modified employing CDM based softening parameters to take account of damage causing tertiary creep. The model is unique in the sense that with the ongoing creep, the evolution of different parameters that are dislocation densities, dislocation mobility, dislocation velocity, internal stress, effective stress and damage evolution is tracked and discussed thoroughly for the first time. Furthermore, the model output is corroborated with experimental creep data of 304HCu steel published in the literature. The predicted values of forest dislocation density, mobile dislocation density, mean free path, internal stress, effective stress, dislocation mobility and dislocation velocity are in the range of $9.23\times10^{11} - 1.01\times10^{13}$ m^{-2}, $9.99\times10^{10} - 4.56\times10^{11}$ m^{-2}, 9.44 – 9.765 μm, 14.01 – 35.47 MPa, 85.99 – 164.5 MPa, $1.682\times10^{-9} - 3.899\times10^{-8}$ $Pa^{-1}s^{-1}$ and $6.48\times10^{-11} - 1.054\times10^{-9}$ m/s, respectively, at the end of simulation.

Keywords: Creep modelling, Dislocation density, Dislocation mobility, Creep damage, Internal stress.

Development of New Ni-Ti based Shape Memory Alloys using Machine Learning Approach

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Conventional experiment based approaches to identify new materials with target properties takes huge time and cost. It is noted that in few cases, it takes close to a decade to realize a product based out of a new material. With the advent of machine learning methodologies, materials development has been accelerated thus reducing the number of experimental trials required. Machine learning (ML) also captures the complex relations hidden in different material systems and has predictive advantage over traditional constitutive modelling as it employs surrogate modelling.
Shape memory alloys (SMA) are class of smart materials that can be trained to attain certain shapes upon specific stimulus. They have widespread applications like in actuators, passive sensor systems, medical applications such as stents, self-healing composite material structures etc. The performance of the SMA in any application is highly influenced by the transformation temperature from martensite to austenite phase and vice versa and the associated thermal hysteresis (shifts in the transformation temperatures in heating & cooling cycles).
The aim of this work is to come up with new Ni-Ti based shape memory alloy compositions (having the aforementioned alloying elements) with minimum hysteresis value (less than 10 K) in a given transformation range using purely machine learning approach. Considering different possibilities of ternary and quaternary systems, data for training the ML Models was collected from existing literature and linear, polynomial, support vector regression (with three different kernels) were trained on the data and predictions were made for known alloys to validate the models.
New and unexplored Ni-Ti based SMA compositions with minimum hysteresis in a transformation range were found out using Efficient Global Optimization (EGO) selector.

Modelling Hole Expansion Ratio of Dual-Phase Steels

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Dual-Phase (DP) Steels are used extensively in automobile bodies like the chassis of cars. While they have a good strength-ductility combination and hence crashworthiness, they are known to suffer from poor non-uniform elongation under complex tri-axial states of stress. This is reflected in their low Hole Expansion Ratio (HER). The resistance of materials to fracture at the edge of a hole is determined using the (HER) test. This study has two objectives: a) macro-mechanical modelling of HER tests to quantify strains and stress distributions for various macro-mechanical properties of DP steels and various external parameters like hole diameter and punch radii; b) micro-mechanical modelling of a miniaturised HER test by explicitly incorporating the ferrite-martensite microstructure and their individual properties to predict initiation of damage during an

HER test. We use finite element modelling for the study, using inputs from experimental measurements of tensile behaviour of DP steels, as well as nanoindentation response of individual phases. Finally, we validate the HER simulation results with available experimental data from the literature.

Traction Separation Curve for Ni Base Hardfacing Alloy-Substrate Interface Grain Boundary by Ab Initio Calculations

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Ni base hardfacing alloys are widely used as a surfacing material to protect liquid sodium cooled fast breeder reactor core components from wear of mating metallic surfaces. Plasma transfer arc process is used to overlay the components with hardfacing alloys and there is a possibility of formation of cracks in the coating under the high weld induced stress. Under loading these pre-existing cracks in the overlay will advance to the bimetallic interface created by welding. Upon Further loading the crack may propagate to the ductile substrate, may cause spalling of the coating or bifurcate along the interface depending on the interface fracture strength, elastic mismatch between the parent materials, crack incidence angle and the loading rate. Competing crack propagation-deflection behaviour at the bimetallic interface can be efficiently studied using continuum simulations employing cohesive zones. Accuracy of these simulation results depends on the traction separation law used to specify the cohesive constitutive relationships. The objective of this work is to obtain cohesive zone parameters that can be used to specify the constitutive response of the weld interface using ab initio density functional theory calculations. A uniaxial tensile test within the framework of density functional theory is performed on a simple structured, low energy face-centred cubic Ni grain boundary with Fe impurity. Energy-separation curve for the grain boundary under increasing tensile load is computed from the ab initio tensile test. The critical tensile stress and the fracture energy are obtained from this curve. These parameters are then incorporated in the cohesive zone model of crack propagation at the hardfacing alloy-substrate interface.

Modelling Microstructure Evolution during Recrystallization using Cellular Automata

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Recrystallization is known to significantly affect the microstructural characteristics and mechanical properties of the material. In this work a generic tool was developed to simulate microstructure evolution during both static (SRX) and dynamic recrystallization (DRX). The cellular automata (CA) approach was used as it is simple to implement, computationally less demanding while providing reasonable accuracy. The model takes in an initial microstructure as an input and simulates microstructure evolution under a user-defined thermomechanical processing environment. The recrystallized grains are nucleated on the boundaries of the deformed grains with empirically obtained nucleation parameters. The grain growth is driven by the grain boundary pressure which is a consequence of gradients in dislocation density across the grain boundary and anisotropic surface energy of the grain boundary. The capture rules are based on a Neumann neighbourhood definition. The model was benchmarked against existing literature on Ni-based super-alloys. The flow curves and microstructural features predicted by this model were found to agree well with experimental results. This model should serve as a tool to study recrystallization under different thermomechanical environments and different initial microstructures. The model is currently being extended into 3D and physics related to GB pinning by γ' phase is being incorporated.
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Titanium Alloy Development using Machine Learning Guided by Physical Metallurgy Principles

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Faster discovery and development of materials requires open innovation. Traditional methods i.e. computational modelling and experiments take enormous time as well as these are bounded by their theoretical basics and experimental conditions. Material Genome Initiative attempts to solve this problem, which aims at combining experimental methods, simulations and database analysis. With the help of this initiative machine learning (ML) may assist in screening of new materials at a lower cost and time. In the present work, an attempt has been made to develop a ML model guided by physical metallurgy to design new Ti-alloys. Titanium and its alloys possess high strength to weight ratio, excellent corrosion resistance and good fatigue properties and by virtue of these finds applications as structural materials in aerospace, biomedical and automotive industries. We aim to implement ML as well as genetic algorithm (GA) guided by sound physical metallurgy concepts of electron to atom ratio (e/a ratio), bond order, energy of d orbitals, and stability of alpha and beta phases to develop new alloy compositions with suitable microstructure and superior properties.

Thermodynamic Re-Assessment of Nb-Zr Binary Alloy Systems Assisted by Ab-Initio Calculations

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High Entropy Alloys (HEAs) have emerged as an important class of engineering materials today. Thermodynamic modelling of these multi-component systems based on simple models often overestimates configurational entropy contribution which is taken care by thermodynamic model based on cluster expansion along with cluster variation method (CE-CVM) incorporating short-range ordering (SRO) effects. The quaternary system under investigation here is Nb-Ti-V-Zr which is based on six binary sub-systems, out of which Nb-Zr is re-assessed in this work. Solid solution phases like β (bcc) and α (hcp) are modelled using CE-CVM framework. A hybrid approach of integrating ab-initio technique based on electronic density functional theory (DFT) is used here to obtain thermodynamic data for this binary sub-system. The simultaneous optimization of Nb-Zr phase diagram has been carried out using experimental data from literature and the zero-temperature enthalpy of mixing data generated by cluster expansion using ATAT software coupled with Quantum Espresso. The similarities and differences between previous assessments and our results are also discussed.

Effect of Post-Heat Treatment on Stress Corrosion Cracking Behaviour of Selective Laser Melted Inconel 718 Alloy

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Additive manufactured alloys show microstructural anisotropy along various directions due to the unique layer by layer melting of metals by laser. These microstructural heterogeneities can affect the corrosion and stress corrosion cracking (SCC) behaviour of the additively manufactured alloys. Effect of heat treatment on microstructure and stress corrosion cracking behaviour of selective laser melted (SLM) Inconel 718 has been studied. Microstructural analysis of SLM Inconel 718 was carried out in as printed (AP), stress relieved (AR), AR+ solution treated and aged (STA) and AR + hipped + STA conditions. Potentiodynamic polarisation and electrochemical impedance studies were carried out in 3.5 wt. % NaCl to evaluate the corrosion resistance along various directions. Stress corrosion cracking tests were carried out to evaluate the effect of microstructural anisotropy on the SCC susceptibility of IN718 in AR+STA and AR+HIP+STA conditions. Slow strain rate tests have been carried out in air and 3.5 wt.% NaCl solution to evaluate the SCC susceptibility index of Inconel 718. The properties were compared with conventionally produced wrought Inconel 718. The fracture mechanism was analysed using scanning electron microscopy of the fracture surface.

Study on Surface Cracking and Interfacial Delamination of Metallic Coatings using a Tension Test

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Surface cracking and interfacial delamination of metallic coatings, deposited by high velocity oxy-

fuel technique, have been investigated under tension test. Local strain distribution has been determined in the coating and substrate by digital image correlation for increasing applied global strain and, results reveal that coating and substrate shows same strain until the elastic limit of the substrate is reached. As the substrate is plastically deformed interface delamination takes place in the metallic Ni and Ni-5Al coatings when 0.05 and 0.027 strain is reached in substrate respectively while in NiCrAlY coating surface crack forms at 0.016 strain and delamination of coating starts at 0.035 strain in substrate. Results also show no plastic deformation occurs in these metallic coatings throughout the test. Numerical simulations have been used to determine stress distribution in the coating, substrate and at the interface, to quantify the fracture strength of the coating and interfacial shear strength, based on the failure mode experimentally observed.

Tribocorrosion Behaviour of Ultrafast Laser Surface Textured Ti-6Al-4V

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The present study concerns understanding the tribocorrosion behaviour of ultrafast laser processed Ti6Al4V processed using a pulsed laser with the pulse duration of 3 ps and 100 fs at a frequency of 10 kHz, laser power of 100 mW and 1 W, and a line spacing of 20 □m, 60 □m, 100 □m, respectively. A detailed study included understanding the microstructure and the effect of laser processing on surface topography and microstructure and residual stress. A detailed study of tribo-corrosion behaviour was undertaken using a tribocorrosion testing unit in the presence of Hank's solution. Finally, the mechanism and mode of failure by tribo-corrosion was established by correlating the post tribocorrosion microstructure with the kinetics of material loss and the coefficient of friction. The results showed an increased wear resistance in terms of significant reduction in wear volume, reduction in specific wear rate and reduction in coefficient of friction in the ultrafast laser textured Ti6Al4V samples as compared to as received Ti6Al4V with a maximum reduction in the sample processed with 1 W laser power,100 fs pulse duration with 20 □m line spacing.

Keywords: Ti6Al4V, ultrafast laser processing, tribocorrosion, microstructure, coefficient of

friction, mechanism.

Effect of Process Parameters on Co-deposition of Ni and Al in Cold Sprayed Coatings of Ni/Al Mixtures

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In this study, co-deposition of Ni and Al powder mixtures was studied. Nickel and aluminium powders were mixed in atomic ratios of 20:80, 40:60, 60:40 and 80:20 and cold sprayed on Al substrate using N_2 gas at various gas pressures (3 MPa, 5 MPa and 6 MPa) and gas temperatures (400 ℃, 500 ℃ and 600 ℃). The effect of cold spray process parameters and feedstock composition on the composition of the coating, overall deposition efficiency (DE) and co-deposition efficiency (CDE) of Ni/Al was analysed. Optimum spray parameters and composition of the feed powder were determined for obtaining compositions closer to NiAl phase in the coating. Coatings of mixtures rich in Ni showed good bonding at the interface. Weight percentage of Ni in the coatings is found to be higher than the weight percentage of Ni in feedstock powder which could be due to the bow shock effect which deflected the light Al particles. Among the four compositions, 20:80 powder mixture showed higher efficiency of Ni deposition. The higher amount of Al in the mixture provided adequate soft matrix for the Ni particles to embed easily in the coating. Increasing Ni content in the feed mixture resulted in lower coating thickness, lower overall DE and lower CDE of Ni. Increasing temperature and pressure resulted in higher particle velocity which subsequently helped in increasing Ni concentration of the coating. The variation in Ni concentration from feed powder to coating reduced with increasing Ni content in the feed. The raise of pressure from 5 MPa to 6 MPa has shown less effect on CDE of Ni with increasing temperature. Macro-hardness of the coatings increased with increasing pressure, temperature and Ni content in the feed mixture.

Effect of Annealing Time on Coating Microstructure Evolution and Electrochemical Behavior of Galvannealed Interstitial-Free Steel

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The application of galvannealed (GA) steel sheet in automobile parts is preferred as it exhibits superior spot weldability, corrosion resistance and paintability than galvanized (GI) steel sheet. This is mainly due to the formation of the favorable Fe-Zn intermetallic phase layers in the coating microstructure during annealing treatment of the GI sheet at specified temperature and time. The present study deals with the effect of holding time (10, 20, and 30 sec) at a fixed annealing temperature of 500 ^{o}C on the formation of various Fe-Zn intermetallics during galvannealing treatment of galvanized coating of interstitial free steel, and its correlation with electrochemical behavior in a freely aerated 3.5% NaCl solution. The X-ray diffraction (XRD) analysis of the as received GI as well as GI specimens annealed at a fixed temperature for varying times reveals the presence of pure zinc (Zn) and various Fe-Zn intermetallic phases in the coating structure, respectively. The microstructural analysis of the GI coatings annealed at a fixed temperature has indicated the transformation of zeta (ς) phase (elongated rod type) to delta (δ) phase (compact type) with an increase in galvannealing holding time. Accordingly, the GA coating surface is associated with homogeneously flattened with craters degeneration. It is noted that the GA coating prepared at galvannealing time of 30 sec has the lowest corrosion rate of 0.184 mm/yr as compared to GA specimens annealed for 20 sec (0.214 mm/yr) and 10 sec (0.227 mm/yr) durations. It has been observed that the dominance of compact and crater-free coating surface morphology along with the lowest zeta to delta (ς/δ) phase fraction results in the lowest corrosion rate of the GA coating at galvannealing time of 30 sec.

Keywords: Galvannealed steel, Fe-Zn intermetallic, Microstructure, Corrosion.

DC and Pulsed Electrodeposition of Zn-Ni Alloy Coatings on IF Steel Substrate from Acidic Chloride Baths

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Electrodeposited Zn-Ni is one of the best Zn alloy coating on steel that provides superior corrosion performance as well as functional properties like wear resistance and microhardness [1]. In the field of electrodeposition, a new deposition technique called pulse current electrodeposition has gained much popularity over conventional Direct Current (DC) deposition as it is known to produce coatings with improved morphology resulting better corrosion properties. The aim of this research is to study the effect of pulse plating parameters and the bath composition on the coating properties. Zinc-nickel coatings were electrodeposited galvanostatically on steel substrates from acidic chloride baths. Variation in zinc and nickel concentration was studied. All the deposition parameters were optimised in-terms of both dc and pulse along with duty cycle and frequency to achieve improved morphology with desired deposition kinetics and superior corrosion properties. Microstructure of the coatings were investigated showing coarse globular and porous structures for DC deposits and finer, compact and needle like structures for pulsed deposits with improved properties. All the coatings were analysed through XRD to study phase analysis to investigate the more corrosion resistive phases resulting a superior Zn-Ni alloy coating solution through electrodeposition.

Keywords: DC and pulse electroplating; Coating morphology; Corrosion; Deposition Rate, Zn-Ni alloy coating.

Repeatability of Friction and Wear of Different Material Pairs at 1000 °C

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High temperature tribology (>600 °C) affects operational efficiency and maintenance burden in metals, mining, power generation and transportation industries. However, temperatures of 1000 °C pose a significant challenge to tribometer design and operation. In addition, the repeatability and reproducibility of test results are difficult to achieve and till date there is no agreement on reference materials for high temperature tribology. This leads to a lack of "faith" on data generated from advanced materials. In this study, we have investigated the friction and wear behavior of six candidate tribo-pairs. The samples used were in the form of balls (silicon nitride, sapphire, alumina) and disks (Inconel 725, gas pressure sintered silicon nitride). The tests were conducted in unidirectional sliding motion (rotation), under 5 N load, both at ambient temperature and 1000 °C. The repeatability of friction and wear results varied with the test temperature: at room temperature, friction showed greater repeatability than wear (average coefficient of variation of 15.77% and 38.97%, respectively); at 1000 °C, the average coefficient of variation for friction decreased to 8.66%, but the wear results were more scattered, with an average coefficient of variation of 109.54%. The recommended reference materials at 1000 °C based on lowest coefficient of variation from the candidate tribo-pairs were: alumina on Inconel 725 for wear (COV < 10%) and sapphire on gas pressure sintered silicon nitride for friction (COV < 5%).

Novel Hybrid Sacrificial Anodes based on High Phosphorus Pig Iron and Zn for the Cathodic Protection of Steel

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In the present work, a series of novel hybrid sacrificial anodes consisting of high phosphorus pig iron and Zn with the stoichiometry of xP-yZn (x=1.5, 3.5, 8.0 wt%P and y=10, 20, 30 wt% Zn) has been synthesized and their feasibility as a sacrificial anode for the cathodic protection of mild steel was investigated in 3.5% NaCl solution. All the hybrid anodes have shown more negative potential below the protective potential of mild steel (– 0.778 V with reference to saturated calomel electrode) in seawater. The anodic capacity and efficiency of all the anodes have been found to be greater than 760 Ah/Kg and 80%, respectively, which is comparable to the commercial Zn sacrificial anode. The polarization resistance of all the hybrid anode samples has also been found to be much lower as compared to the mild steel and the commercial Zn anodes, suggesting their more active dissolution behavior. The localized segregation of Zn and large cathode-to-anode area ratio in the microstructure attribute to the active behavior of the hybrid anodes. A mechanistic approach has been adopted to understand the dissolution mechanism and reason for the active

behavior of the hybrid anodes. The proposed model for the corrosion mechanism of the hybrid anodes illustrates uniform dissolution behavior, which is an important characteristic for an effective sacrificial anode. The present hybrid anodes have also been found to be equally efficient, highly economical and commercially more feasible as compared to the previously developed hybrid anodes and conventional Zn anodes.

Keywords: Corrosion, Hybrid sacrificial anode, Cathodic protection, Anode capacity.

Corrosion Resistance of Fe-based Metallic Glass Composite Coating: Role of Amorphicity and Porosity

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The unique combination of mechanical properties and corrosion resistance makes Fe-based metallic glass (MG) composite coating prepared using thermal spraying processes a viable candidate for long-term protection of different components in various applications. Presence of crystalline phases in glassy matrix of the MG composite coating improves the mechanical properties, at the same time these phases can cause degradation in the corrosion behavior. Apart from this, porosity generated during spraying process is another major inevitable defect in such coatings. In general, the above-mentioned attributes (viz. devitrification and porosity) have detrimental effect on the corrosion properties of MG composite coatings. Nevertheless, it is still ambiguous to identify a microstructural characteristic between amorphicity and porosity, which would have a higher impact on the corrosion properties of thermal sprayed Fe-based MG composite coating until now. Hence, for resolving this issue, in-situ MG composite coatings were prepared by high velocity oxygen fuel spraying, along with two melt-spun ribbons with varying level of amorphicity, viz. (i) completely amorphous and (ii) similar in amorphicity to the coating. The idea behind this was to determine the individual effects of amorphicity and porosity with regards to deterioration in corrosion properties of such coatings. The results of electrochemical characterizations along with Raman analysis and Auger electron spectroscopy established that the corrosion behavior of Fe-based MG composite coating was substantially affected by the reduced amorphicity aspect rather than the porosity. A schematic illustration has been presented to simplify

the understanding of corrosion-induced degradation mechanism for Fe-based MG composite coating, as shown in Figure 2. This work will eventually assist in the development of new MG composite coatings possessing enhanced corrosion properties.

Keywords: Fe-based metallic glass composite coating, Thermal spraying, Amorphicity, Porosity, Corrosion behaviour, Passive film.

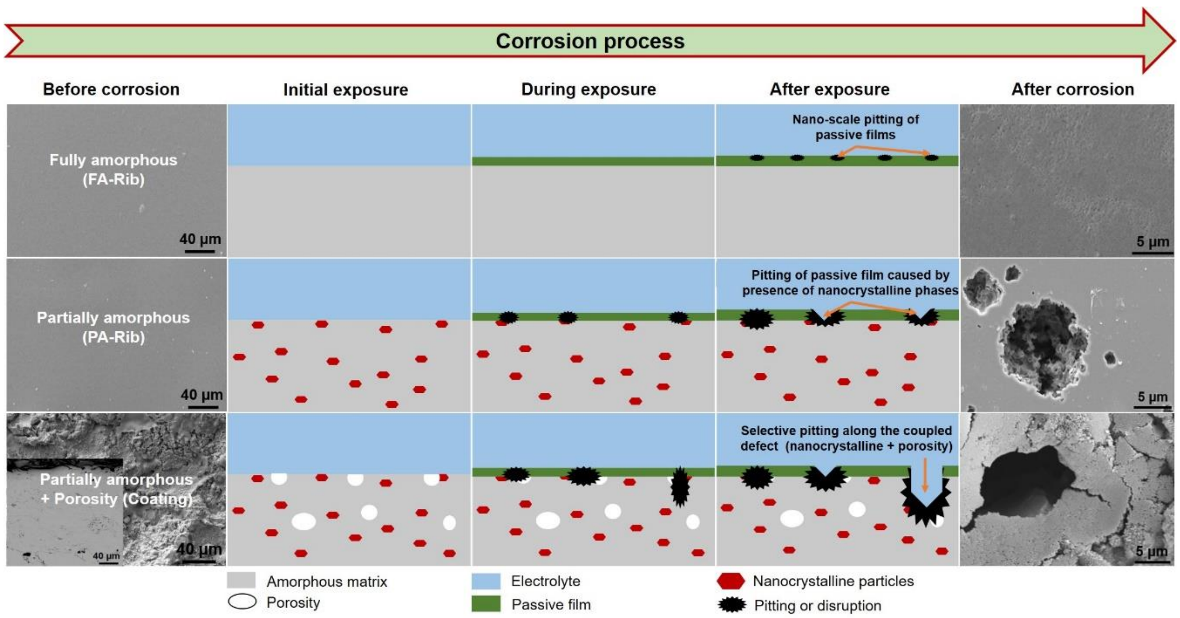

Figure 2. Schematic illustration of the corrosion process in Fe-based MG composite coating: correlation between the corrosion behavior and the microstructural features.

Studies on Structure and Texture Evolution in B-added Modified 9Cr1Mo (P91) Steel with varying Boron Concentration

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In this work we have dealt with concentrated alloys of B added P91 steels in order to understand the segregation mechanism of B in the steel. It is intriguing to completely understand the segregation mechanism of B in steels. Boron addition to P91 enhances its creep resistance property and hardenability for various high-temperature applications. In this work, different phases formed after the boron addition to P91 were calculated using the Thermo-Calc. software. The $(Fe, Cr)_2B$ phase fraction started dominating the α-Fe matrix beyond 2.5 wt% boron in P91. Arc melting technique was used to prepare Mod. P91 together with 5 wt%, 2.5 wt%, and 0.5 wt% boron. Phase identification using XRD confirmed the $(Fe, Cr)_2B$ phase formation and preferred orientation along the (002) plane in 5 wt% boron added P91. The microstructural and microchemical studies of the samples were carried out using SEM-EDS. The grain size of $(Fe, Cr)_2B$ ranges from 46 µm to 2 µm, and with reduced boron concentration, $(Fe, Cr)_2B$ grain size reduction is observed. Segregation of this intermetallic phase in the Prior Austenite Grain Boundaries (PAGBs) is prominent in 0.5wt% boron added P91. The EBSD studies of these samples showed strong texture for the $(Fe, Cr)_2B$ phase. The 5 wt% B added P91 behaved like a composite material forming $(Fe, Cr)_2B$ phase reinforcement in α-Fe phases, with distinct hardness values. The $(Fe, Cr)_2B$ and α-Fe phase showed a hardness of 2541 HV and 618 HV, respectively. Even though the hardness for the $(Fe, Cr)_2B$ phase is high and expected to be brittle, it still shows ductility. Detailed TEM results confirming precipitate formation will be presented at the conference.

Influence of Cell Geometry on Impact Response of Closed Cell Al Foam

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Closed cell aluminium foam is considered to be suitable for impact applications where high energy absorption and reduction of transmitted force (TF) are paramount requirements. Several factors influence TF viz. density, cell integrity, velocity of impact, shape of the indenter etc [1]. Propagation of elastic waves which constitutes TF during an impact is governed by cell geometry and its integrity [2]. However, there are no reports of the role of cell geometry on the transmitted force so far. In view of this, the present study describes impact response of aluminium foam at broad range of impact velocities as a function of cell geometry.
The study begins with illustration of closed cell aluminium foam geometry which is observed to be hexagonal for foams of density less than 0.55 g/cm^3 and spherical for foams of density greater than 0.63 g/cm^3. Impact response was studied by using three different test equipment, i.e. an

instrumented drop impact machine, a gas gun and a special free-fall test rigs where drop energy was varied from 9 J to 90 kJ and impact velocity from 2 to 400 m/s. The tips of indenter were hemi-spherical, spherical and flat shaped which resulted in different deformation characteristics and consequently, varied TF values. In general, peak TF increased gradually with increasing density which was attributed to the increase in the strength of foam with density. Peak TF also increased with increase in impact velocity particularly for hexagonal foams. The observed velocity sensitivity was correlated with the deformation mechanics of the hexagonal cell geometry. It was explained that the hexagonal cells displayed delayed bending behaviour due to the inertial compression of cell walls prior to their bending. However, the impact tests on spherical foams did not show this trend i.e. peak TF remained nearly constant at all the impact velocities. The reason for this behaviour was due to the fact that the spherical cells deformed only by bending without any compression of cell walls which had enhanced strength [3]. Thus, the results in this study demonstrate the relation between TF and the cell geometry during impact deformation of Al foam along with the effect of indenter shape which is significant for designing of impact absorbing structures for protection engineering.

Keywords: Aluminium foam, impact, velocity sensitivity, transmitted force, cell geometry

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Achieving Isotropic Elastic Modulus and Hardness in Anisotropic Ti-6Al-4V Alloy

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In spite of immoderate applications in aerospace and biomedical fields, the performance of Ti-6Al-4V alloy has been severely constrained by its anisotropic mechanical properties owing to the hexagonal close packed structure. Hence, a processing route was designed to obtain isotropic properties in this material. The processing route involves generation of martensite by water quenching from 920 °C in a prior hot deformed material. The extent of deformation and quenching temperatures significantly influence the morphologies of the martensite. The martensite (α′) formed from the β phase has nearly equal distribution of multiple variants in the form of fine laths. A cold rolling (20 pct.) operation prior to the heat treatment at 600 °C for 4800 s accelerated the kinetics of martensite decomposition. The microstructure of the final heat-treated material is characterized by the formation of discontinuous and fine β phase along the interfaces of α laths instead of thin lamellar β. Nanoindentation studies demonstrate the generation of isotropic elastic modulus and hardness in these materials. These isotropic properties are attributed to the variant selection in martensitic evolution and fine structure that results from the decomposition of martensite.

Relative Effect of B and N Concentrations on the Microstructural Stability and Creep Properties of Modified 9Cr-1Mo steel

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Present study systematically varied different combinations of boron and nitrogen (B free and 500 ppm N, 25 ppm B and 90 ppm N, 70 ppm B and 108 ppm B, 90 ppm B and 90 ppm N, 100 ppm B and 20 ppm N) to understand the influence of composition on improving microstructural stability and creep resistance (650 ºC, 120 MPa) of modified P91 steel widely used in nuclear power plant applications.The Auger Electron Spectroscopic (AES) analysis reveals the enrichment of B within the $M_{23}C_6$ precipitates at the vicinity of prior-austenite grain boundaries in B added steels both in normalized and tempered specimens and also in creep tested specimens. The 70 ppm B steel with 108 ppm N showed the best creep resistance (rupture time as high as 1536 h and minimum creep-rate as low as 1×10^{-5} / h), followed by 90 ppm B, 90 ppm N steel and 100 ppm B, 20 ppm N steel

respectively. Addition of B reduced the $M_{23}C_6$ precipitate coarsening rate which gives better pinning of grain boundaries/sub-boundaries and thereby provides better microstructural stability and optimum addition of nitrogen can form highly stable MX precipitates. Study revealed too low boron or too high nitrogen is detrimental to creep strength of grade P91 steel, an optimum concentration of 70 ppm to 100 ppm B and 90 ppm to 110 ppm N is necessarily recommended for better creep life.

Keywords: Modified 9Cr-1Mo steels, Boron concentration, Nitrogen concentration, Precipitate stability, Creep resistance.

Mechanical Behaviour of Ultrafine-grained SS304L Produced by Reversion of Strain Induced Martensite

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Ultra-fine grained SS304L was produced using the technique of reverting strain induced martensite. In this method, cold deformation was given to the specimen to form martensite and subsequent reversion treatment to form an austenite phase with ultra-fine grains. The commercially available plate of SS304L of composition 0.03C, 1.065Mn, 0.54Si, 18.27Cr, 8Ni, 0.31Cu, and 0.320Mo was rolled up to an effective strain of ~2.0 (~87% rolled). This was done by dipping the plate in liquid nitrogen, removing and rolling it to a few passes; this process was repeated till the final effective strain of 2 was achieved. Subsequently the rolled plate was thermally treated at 700 °C for 30 min. The grain size obtained after the thermal treatment was 800 nm. The flow behaviour of this ultra-fine grained (ufg) SS304L was studied in compression at the strain rate of 5 x 10^{-4} and 1000 sec^{-1} and was compared with that of the coarse grained SS304L. The evolution of strain induced martensite with strain in ufg-SS304L was determined using Ferrite-scope. The yield strength of the rolled+reverted condition was found to be 850 and 950 MPa at the strain rate of 5 x 10^{-4} and 1000 sec^{-1}, respectively. The strain hardening behaviour of ufg-SS304L showed absence of secondary hardening as compared with coarse grained SS304L at the strain rate of 5 x 10^{-4} sec^{-1}. At higher strain rates of 10^3 sec^{-1}, strain hardening rate with strain was lower for ufg-SS304L in comparison to that of the coarse grained SS304L. The strain rate sensitivity for ufg-SS304L was lower in comparison to that of coarse grained material.

Development of Ring Forgings of 11Cr-10Ni-2Mo-1Ti PH Martensitic Stainless Steel for Rocket Motor Application

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A programme for indigenous manufacturing aircraft quality, 11Cr-10Ni-2Mo-1Ti Precipitation Hardening Martensitic Stainless Steel (PHMSS) forged rings was successfully completed at Mishra Dhatu Nigam Limited (MIDHANI), Hyderabad, for making components of aero application. This alloy gains advantage by its superior mechanical and stress corrosion resistance properties than 17-4PH and 15-5PH stainless steels. Components of this alloy can be air hardened with relatively less distortion. Balance between high strength and toughness has been a difficulty in this alloy in lieu of the effect of chemistry and heat treatment. Data analysis of earlier processed forged bars indicated that material is sensitive to chemical composition and processing gets hampered by presence of inclusions. Therefore close control of chemistry and processing conditions is a challenge in this alloy. To achieve the desired chemistry, this alloy was primary melted in Vacuum Induction melting (VIM) and secondary melted in Vacuum Arc Remelting (VAR). Combination of cogging, drawing and upset forging followed by punching and saddle forging was adopted to realize the rings. Solution annealing heat treatment was carried out at 965 °C (calculated using JMAT software). Test coupons were cut from the solution annealed rings for further detailed microstructure and mechanical property evaluation. Tensile testing was carried out at 27 °C, 200 °C, 350 °C and 450 °C on age hardened samples. High strength and toughness could be achieved with calculated conception of Mo and Ti and a controlled balance of precipitate size and reverted austenite during age hardening. B and Zr were microalloyed to enhance grain refinement as well as to improve hardenability. The optimized age hardening cycle was 530 °C, 4 hr soaking and air cooling to achieve desired mechanical properties. Optical and SEM/EDS techniques were used for microstructure and fractography analysis.

Characterization of Fracture Resistance of Modified 9Cr-1Mo Steels

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The deformation and fracture resistance of Modified 9Cr-1Mo steel was evaluated at test temperatures in the range 300-550 °C. The tensile testing and fracture resistance (J-R curves) was evaluated in the test temperature range 300-550 °C. In this temperature range, yield strength was in the range 450-600 MPa and tensile strength was in the range 470-700 MPa. In this temperature range minima in ductility and peak in strain hardening exponent was observed. From the J-R curves, J1c values were determined. The fracture toughness was observed in the range 200-300 kJ/m^2. Minima in fracture resistance and tearing resistance were observed. The results are explained based on fractographic observations.

The Quest for High-Strength and High-Ductility Composite Materials

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Friction stir processing (FSP) is a solid state technique used for material processing. Tool wear and the agglomeration of ceramic particles have been serious issues in FSP of metal matrix composites. In the present study, FSP has been employed to disperse the nanoscale particles of a polymer-derived silicon carbonitride (SiCN) ceramic phase into copper by an in-situ process. SiCN cross linked polymer particles were incorporated using multi-pass FSP into pure copper to form bulk particulate metal matrix composites. The polymer was then converted into ceramic through an in-situ pyrolysis process and dispersed by FSP. Multi-pass processing was carried out to remove porosity from the samples and also for the uniform dispersion of polymer derived ceramic particles. The microstructure during FSP evolved by discontinuous dynamic recrystallization. In the composite, fine ceramic particles pin the grain boundaries, preventing grain growth resulting in a fine grain (2 μm) structure being retained. The composite microstructure was characterized by

equiaxed grains with narrow grain size distribution and a high fraction (> 80%) of high angle grain boundaries. The combined effect of grain refinement and ceramic particle incorporation lead to a twofold improvement in the proof stress of the composite (201 MPa compared to 98 MPa of base copper). The ultimate tensile strength improved by 33% and there was small drop in the ductility of the composite when compared to base Cu. Kocks-Mecking plot of the composite showed stage III of work hardening. The results indicate a uniform distribution of ~ 100 nm size particles of the ceramic phase in the copper matrix after FSP. The nanocomposite exhibits a fivefold increase in microhardness ($260HV_{100}$) which is attributed to the nano scale dispersion of ceramic particles. A mechanism has been proposed for the fracturing of PDC particles during multi-pass FSP.

Fabrication of MWCNTs Reinforced Iron Metal Matrix Composite Fabricated by Conventional Powder Metallurgy: Effect of Wet Milling and MWCNTs Content

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The present research reports fabrication of iron reinforced with 0.5, 1, 2 and 4 vol. % multi walled carbon nanotube (MWCNTs) MMC by powder metallurgy involving mechanical milling in wet (toluene) condition followed by cold compaction and conventional sintering at 900, 1200 and 1300 °C for 2 hours under commercial argon. The iron-MWCNTs composite powders are milled in a high energy dual drive planetary mill for 10 hours and then characterized. X-Ray diffraction (XRD) study exhibits formation of ferrite, austenite and iron carbides (Fe_3C and Fe_7C_3) after 10 hours of milling. However, iron carbides are disappeared and iron oxide (Fe_3O_4) is formed along with ferrite after sintering. Maximum relative density of 90 %, Vickers hardness of 350 HV and compressive strength of 800 MPa are achieved for Fe-1 vol. % MWCNTs composite sintered at 1300 °C for 2 hours.

Keywords: Metal matrix composite; MWCNTs; wet milling; powder metallurgy

Carbon fibre Reinforced Zirconium Diboride (C_f-ZrB_2) Ultra High Temperature Ceramic Matrix Composite

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Zirconium diboride (ZrB_2) is classified as ultra high temperature ceramic (UHTC) material (melting point > 3000 ^{0}C). It has impressive properties like high thermal conductivity (85 - 90 W/m/K at room temperature) and strength retention at high temperature. It has been emerged as the potential candidate for extreme environments associated with the hypersonic futuristic technology, atmospheric re-entry technology and for thermal protection systems. The major limitations for practical applications are the low fracture toughness and poor thermal shock resistance of the monolithic ZrB_2 and its particulate composites. To overcome these limitations, UHTC require conversion to a more damage tolerant material. One way to produce damage tolerant components is to replace it with the continuous fibre reinforced ultra high temperature ceramic matrix composite (UHTCMC). However, the processing of the continuous fibre reinforced ZrB_2 ceramic matrix composite is a challenging task and the processing methodologies for the development of UHTCMCs based on ZrB_2 continue to evolve. The present investigation focused on the development of a process methodology for C_f – ZrB_2 composite. Processing steps include slurry infiltration, curing, pyrolysis and high temperature pressureless sintering. The effect of carbon fibre architecture (2D /2.5D) on the mechanical properties was studied. There was a drastic improvement in the mechanical properties of the 2.5D composite over the 2D C_f – ZrB_2 composite. This is due to the minimization of the de-lamination between the carbon fibre and the ZrB_2 matrix layers in the 2.5D C_f - ZrB_2composite.

NiAl Intermetallic Composite – A Review on Process Property Co-Relationship

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The NiAl intermetallic matrix reinforced with a combination of brittle and ductile phase are emerge as engineering material for high temperature applications. Its excellent resistance to oxidation and high thermal stability, high creep strength, comparative low density makes it a appropriate choice for high temperature applications especially in aerospace, automobile and power sectors. TheB2 intermetallic structure of NiAl makes it structurally stable even at critical higher temperatures that are of engineering importance. Unfortunately, the major drawbacks to the wide applicability of such intermetallic is its poor room temperature fracture toughness. The shortage of slip systems and the difficulty of slip transmission across grain boundaries are the key obstacle for the toughness enhancement of NiAl at room temperature. There is also some major concern for the synthesis of these materials which hinder the synthesis by conventional casting methods. Several alternative routes have been presented in literature for the production of NiAl based composites. In this review, the various efforts of researchers in solving this major limitation of nickel aluminides are evaluated and summarized. This overview focuses mainly on the most recent approaches for the processing of NiAl IMCs, and enlightens the processing-structure-properties relationships.

Keywords: Intermetallic Composite, Intermetallic toughening, High temperature properties.

Mean-Field Based Micromechanical Models to Investigate the Effect of Reinforcement Shape and Orientation on the Effective Electroelastic Properties of Polymer Composites with Orthotropic Matrix

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Computational micromechanics have proved to be essential towards theoretical estimation of effective electroelastic properties of piezoelectric composites, thereby complementing experimental efforts. The estimation of the overall properties of piezoelectric composites using analytical micromechanics can be performed by considering the properties of the individual phases, such as (i) material properties of matrix and reinforcement(s) and (ii) shape, orientation, and distribution of reinforcement(s). However, analytical micromechanical models for complex materials such as composites with orthotropic matrices are yet to be explored fully. As such, we present the results of two studies on the effect of reinforcement shape and orientation on the effective elastic, piezoelectric and dielectric properties of 0-3 and 1-3 piezoelectric polymer composite with orthotropic matrix. Two analytical micromechanical models were used: (i) the Incremental Self Consistent method and (ii) the modified Eshelby-Mori-Tanaka model. In the first study, four different types of shapes of reinforcements, viz. (a) circular cylindrical, (b) elliptic cylindrical, (c) ellipsoidal and (d) spherical were considered, and the analysis was performed for unidirectional composites. In the second study, the effect of reinforcement aspect ratio and orientation on the overall properties of piezoelectric polymer composite was investigated using a method based on the Eshelby-Mori-Tanaka micromechanics, and the effective properties of ellipsoidal reinforcements with four different aspect ratios were determined. The properties for all the composite systems were determined at five discrete spatial orientations of reinforcement as well as for randomly oriented reinforcements. As an example of piezoelectric polymer composite with orthotropic matrix, the Polyvinylidene Fluoride (PVDF) / Lead Zirconate Titanate (PZT-7A) composite system was considered for both studies. The results provide interesting insights into choice of appropriate reinforcement geometry and orientation and provides us a platform to compare the applicability of these two micromechanical models.

Elucidating Laser Additive Manufacturing of compositionally graded Stainless Steel-Copper Bulk Structures

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Advances in laser directed energy deposition (LDED) based additive manufacturing established it as one of advanced techniques for fabricating multi-material or compositionally graded (CG) components. Among the different material combinations, stainless steel (SS) – copper (Cu) multi-material component is an enduring research topic for potential applications in tooling industries, power generation unit and cryogenics. However, large difference in thermo-physical properties and lower solubility of iron (Fe) in Cu makes the fabrication of SS-Cu component challenging. These issues lead to crack and porosity at the interface of SS-Cu causing pre-mature failure of engineering components. Thus, a systematic investigation is carried out for fabricating SS-Cu compositionally graded (CG) bulk at 20, 50 and 100% grading percentage by varying process parameters and feed powder composition. Process parameters for depositing CG SS-Cu bulk is identified by depositing bulk structures of individual composition (SS_xCu_{100-x}, X varies as 0, 20, 40, 50, 60, 80, and 100). Further, bulk structures of individual composition and CG Cu-SS are subjected to X-ray differentiation, optical microscopy and mechanical characterization. It is observed that LDED built CG bulk yields desired variation in chemical compositions and mechanical behavior along the build direction as per the designed. In addition, it is observed that 50% graded SS-Cu bulk yields defect free depositions, whereas 20% graded SS-Cu bulk structures yields cracks in lower Cu region. The present investigation paves the way for establishing LDED as one of the techniques for fabricating SS-Cu multi-material component for tooling industry, power plant and cryogenic applications.

Design Optimization of PLA (Polylactic Acid) Lattice in 3D Printing (FDM)

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This paper aims to research study on the factors that affects the design of 3D printed lattice structures prepared using PLA (Polylactic Acid) material in fused deposition modelling (FDM) type 3D printing. The paper is written by studying from basics of filament manufacturing process to types of filament material used for printing in FDM process, and printing parameters of FDM techniques, and characteristics mapping of PLA material is carried out to determine the best parameters for the 3d printing using PLA (80). The printing parameters of PLA includes print temperature (usually between 170 ^{o}C - 210 ^{o}C), layer height of deposition, shell wall thickness, infill density and pattern, print speed, cooling fan speed and support placement. Among the other 16 types of filaments, PLA is easy to print, consumes low energy, does not emit toxic fumes, is stable while printing and biodegradable.

Heat Treatment Studies on Inconel 718 Alloy Processed by Laser-based Powder Bed Fusion (L-PBF) Technique

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In the present study, the microstructures of Inconel 718 alloy processed by laser-based powder bed fusion (L-PBF) techniques subjected to various heat treatments are studied. The as-printed samples were subjected to homogenizing and solutionizing treatments at 1080 °C and 980 °C respectively with two holding times (1 hr and 0.5 hr) each and followed by double ageing treatments. Among all, the combined homogenizing treatment performed at 1080 °C/1 hr with double ageing at 720 °C/8hr + 620 °C/8hr has resulted with highest hardness due to effective dissolution of laves phase into the matrix γ-phase during homogenization treatment and precipitation of strengthening phases during aging as confirmed by XRD results and SEM micrographs. The specimens were further subjected to mechanical studies such as hardness and tensile strength to find the effect of various heat treatments.

Post processing effects on Additively Manufactured Inconel 718 Superalloy

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In the present study, Inconel 718 (IN718) superalloy is fabricated by additive manufacturing process using Selective Laser Melting (SLM) technique. The investigation is focused on the effect of post processing heat treatment on grains morphology, crystallographic texture, precipitates formation/dissolution and correlation with material properties. The As-Printed macrostructure clearly display the nature of melt pool boundaries, comprising of elemental segregations. And the microstructure exhibited columnar morphology with Laves phase precipitation. Laves phase is

responsible for declined mechanical properties of As-Printed material. Therefore, to increase the mechanical properties and dissolve the detrimental Laves phase special heat treatments are required. For this purpose, three different sets of heat treatments were done comprising homogenization, solutionizing and further followed by ageing process. Heat treated microstructure exhibited homogeneously dispersed γ' and γ'' phases, blocky carbides, acicular and plate shaped δ phases depending on various heat treatment processes. X-Ray Diffraction characterize the phase evolution of the specimens. Electron Backscattered Diffraction (EBSD) was used to identify the crystallographic texture development. A significant increase in hardness (by approximately 54%) and tensile strength (by about 45%) with minor setback in ductility were achieved after heat treatments, compared to As-Printed component. This study provides a comprehensive investigation of the post heat-treatments of the Selective Lase Melting of IN718 that can result in an optimized microstructure and mechanical behaviour for particular applications.

Comparison of Corrosion Behavior of Additively Manufactured Ti-6Al-4V Alloys Having Different Meso Structure

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Additively manufactured Ti6Al4V (Ti64) alloys manufactured through selective laser melting (SLM) technique has exhibited a distant mechanical response compared to its wrought counter part due to the higher content of acicular martenstic ά phase. SLM Ti64 coupons printed using different combinations of process parameters offers variety of micro and meso structural features. Using scan spacing of 30 and 60 µm and scan rotation of 67° and 90°, four different types of coupons are produced, which are labeled as scan spacing proceeded by scan direction, like 3090, 3067, 6090 and 6067. In this work, corrosion behavior of following coupons along Build (B) and Scan (S) planes are compared and a significant difference is observed. Correspondingly, optical micrographs also reveal a divergent micro and meso structural features in B and S planes for each of these coupons. Among all samples, B3090 has highest corrosion rate due to higher martenstic ά phase, weaker texture and cuboidal architecture. Coupons with 67° scan rotation have shown far better corrosion resistance in both planes owing to its equiaxed microstructural features.

Microstructure and Mechanical Properties of Additively Manufactured Al20X with Different Heat Treatments

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Al20X^{TM} is among the strongest commercially available additive manufactured aluminum alloys with yield strength of nearly 450 MPa having a 12-15% ductility, at room temperature. The high strength Al-Cu-Ag-Mg alloy comprises TiB_2 particles which enables the successful fabrication of dense parts using the laser powder bed fusion process and hence offers the ability to potentially use this alloys at temperatures beyond other Aluminum alloys. This study involves a detailed characterization of the as printed Al20X alloy and establishing a heat treatment window that ensures thermal stability of the microstructure, as a prelude to evaluating the creep behavior of the high strength Al alloy. Detailed characterization for porosity, microstructure, tensile behavior of the alloy in the as printed and heat treated condition is presented in this study.

Research and Experiments in Non-Destructive Testing

Somina Venkata Surya Brahma Linga Sarma

A non-destructive testing is an examination of an object in any manner which will not impair the future usefulness of the object. For example, under altering magnetic conditions in electrical machine measuring sensors, causes strain hardening, non-recrystallization and coarsening grain size, on BCC slip lines in magnetic iron, causes iron loss in the of form Fe3c on (110) lattice, which results in increasing coercivity, low permeability, decrease of magnetic induction, reduces the performance of these sensors. The magnetic thin films can be used in these sensors. Isolated solute atoms, dislocated-pileups, solid solution strengthening causes increase in grain size. Ferro magnetic substance of Iron is important for increasing magnetic induction. Dislocations, massive blocks, grain size distortion of crystal lattice also causes increasing coercivity. The current non-destructive testing techniques such as Radiography, Magnetic particle inspection, fluorescent penetrant inspection, ultrasonic inspection and eddy current inspection would not support the testing or evaluate parameters such as Iron losses, dislocation-pileups and coarsening grain size. Research should be carried out to find out appropriate non-destructive testing technique to evaluate

these parameters for better performance of these sensors and/or for any other industry needs of similar non-destructive testing technique.

Study on Metallurgical and Mechanical Properties of Eb Welded Heat Treated Super Martensitic Stainless Steel (CA6NM) Material for Cryogenic Applications

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A super martensitic stainless steel near equivalent to CA6NM is a high alloy martensitic stainless steel grade which contains 0.08 % Carbon, 14% Chromium, 7% Nickel, 0.3% Copper and other alloying elements. It offers an excellent zero notch ductility, good corrosion resistance, compatible with liquid oxygen, excellent weldability, very high pressure carrying capacity at cryogenic temperature and thus suitable for making cryogenic components. Welding was performed on a heat treated and demagnetized base metal using autogeneous Electron Beam Welding process. The process parameters were developed is based on the bead on trials and welding trials. Sample plates of 18 mm thick, 150 mm length and 100 mm width were butt joined using EB welding process. During bead on trials on super martensitic stainless steel by EBW process, the problem of electron beam deflection was faced due to residual magnet flux effect. This could be minimised by online correction during trials and finding the beam offset coordinates. Based on that, actual welding program could be modified, otherwise it would cause lack of fusion. Welding of this magnetic material using EBW process even after demagnetization is a challenge. Base metal and weld bead were characterized through various methods such as Optical microscope, Scanning electron microscope (SEM), and X-ray diffraction (XRD). Tensile testing at room temperature (303 K) and cryogenic temperature (77 K) and micro hardness test were carried out. The welding parameters found in the present study are accelerating voltage 60 kV, beam current 55 mA, focus current 519 mA, travel speed 150 mm/min, gun to work piece distance 227 mm and beam oscillation 0.1 mm circular at 1200Hz frequency. The EB weldment have with an average yield strength and UTS at room temperature of 892 MPa and 1153 MPa respectively. Average yield strength and UTS during cryogenic temperature of 1365 MPa and 1573 MPa respectively. The average hardness of base metal is 370HV, weld metal 364HV and HAZ 382HV.

Keywords: electron beam welding, martensitic stainless steel, micro-hardness, microstructure, tensile properties, fractography analysis, XRD.

A Study on Electron Beam Welding of Hermetic Feed Through Connectors with Pressure Vessels

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Hermetically sealed connectors are commonly used in aerospace applications. Hermetic feed through connectors are used in receptacle electrical feed through the pressurized equipment housing in either pressure direction. Hermetic seal generally contains the glass to metal seals but customized ceramic to metal seals are also found in application which withstands a specified amount of pressure and maintains a leak rate below the threshold value. Such types of connectors are welded to the pressure vessels by conventional Gas Tungsten Arc Welding (GTAW). The major task in successful welding of connectors is the control of temperature at the hermetically sealed interface during welding operation. Conventional GTAW process needs multiple starts and stops in order to meet the stringent temperature control requirement of less than 150 °C at a distance of 8 mm from the weldment. Moreover, continuous and multiple spots are created to from a complete circumferential weld. This procedure influences adversely the quality of the weld joint. Thus high energy density welding process such as Electron Beam Welding (EBW) process is attempted.

The objective of this research is to study the electron beam welding (EBW) of hermetic feed through connectors with pressure vessels. The excessive heat input from conventional arc welding processes could damage the connector's hermetic seal while the relatively low welding heat input characteristics of EBW process allows the successful installation and sealing of the sensitive connector to the high pressure vessel. The connector body is made of SS304L and pressure vessel body is made of SS321. There is a major concern to be addressed while EBW of Hermetic Feed Through connectors. The temperature control of the glass-metal interface below the maximum allowed temperature of 150 °C at a distance of 8 mm from the weldment. So, the special attention had to be paid in the overlap regions where double heat input was given. The overlap region had to be lengthy enough to allow smooth keyhole formation but should not be too lengthy to cause temperature rise which can damage the hermetic seal. It was found that the stringent temperature limit maintenance was aided by the implementation of the high welding speed in EBW. The temperature was observed during the welding and detailed microstructure investigations revealed defect free weld. The micro-hardness survey as well as the mechanical property demonstration of the welded sample was carried out. With the confidence of the test and characterization results, the actual feed through connector was successfully welded.

Keywords: Hermetic, Feed through connector, SS304L, SS321, EBW, GTAW, Mechanical properties, Temperature control.

Integrated Experimental and Simulation Study to Modify the Weld Thermal Cycle in Inconel 718 GTA Welds

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Inconel 718 is widely using in power plants, marine and aerospace industries. Although the alloy possesses good weldability, segregation of alloying elements and detrimental phase formation in the fusion zone affect the properties. The segregation of elements and heat affected zone microstructure will depend on the thermal field experienced during welding. The current study establishes the thermal field in gas tungsten arc welds (GTAW) using FEM modelling. A double ellipsoidal heat source model was used, and the boundary conditions were given based on the experimental trials. The weld bead profiles and thermal cycle by varying the heat transfer condition was studied. The simulated weld cycle was correlated with the phase formation using JMatPro®. The validation of FEM modelling was done using an experimentally acquired thermal cycle. The studies show that integrating the FEM modelling reduces the experimental trials and accelerate the welding process optimization. The current study confirms that the detrimental phase formation can be reduced by suitably modifying the thermal cycle by changing welding conditions.

Keywords: Inconel 718, GTAW, FEM modelling, Thermal cycle

Predicting Cracking Susceptibility in Welded Components using Computational Modelling

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Cracking of laser-welded components results from thermal residual stress; volumetric shrinkage (or expansion) during solidification (or melting); and solidification kinetics. Critical strain accumulated in the thin liquid films present at grain boundaries found in the mushy region trailing

the melt pool poses serious concerns to weldability of certain alloys. The solidification range of the alloy, size of the mushy region, thermal strain distribution, and weld parameters are some of the variables that are required to be optimized to control cracking. Hydrogen content in the melt pool (leads to pore formation) and mushy zone ductility are also known to influence the quality of the weld. Currently, a framework is developed to predict cracking of components welded by Gas Metal Arc Welding (GMAW) process. A multiphase transient heat transfer model is used to capture the melt pool shape using computational fluid dynamics (CFD). Elastic-plastic material properties are considered and thermal stress evolution is studied in relevance to cracking susceptibility. The influence of pulsed Gaussian laser heat source on the melt pool characteristics is also investigated. Weld process parameters are correlated with generated residual stress and post-solidification distortion. Phase field simulations are used to predict the microstructure at the solidification front. With the scale bridging introduced to ensure seamless transfer of information between the macroscale and microscale domains, local cracking susceptibility is evaluated.

Keywords: Solidification, Cracking, GMAW, OpenFOAM, CFD, ICME, Multiscale, Residual stress

Influence of Welding Processes on Microstructure and Tensile properties of Weld Joints of Beta (Titan-44) alloy

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Beta-21S (Titan-44) is a metastable beta Ti alloy which exhibits good formability and improved oxidation resistance and creep strength till 816 ^{o}C. This alloy exhibits fire resistance to aircraft hydraulic fluids such as Skydrol. Titan-44 is used as ducts in boeing777 and a few aircrafts parts of the Airbus A340. Beta Ti alloys show reasonable welding characteristics but, weldability parameters and processes greatly influence the mechanical properties of the weldments. The weld joints of Titan-44 sheet of 2 mm thickness were fabricated by tungsten inert gas welding (TIGW) and electron beam welding(EBW) processes.
The optimized parameters employed in TIG welding are 10 V, 65 A and welding speed of 0.25 m/min. And the parameters employed in EB welding process are 40 kV, 25 mA and 0.5 m/min. Sound welds with no porosity are obtained and justified with radiographs. Higher hardness values

are obtained in fusion zone (FZ) compared to finer and coarser heat affected zones (HAZ) and base metal in both the EBW and TIGW processes. Higher hardness was observed in EB weld profile compared to the TIG weld profile. The decrease in hardness from FZ to HAZ, are correlated to optical microstructures obtained for both the processes. Tensile tests were conducted for both the TIG and EB weldments at room temperature. The joints fabricated by EBW processes exhibited higher strength and good ductility compared to TIGW-joints. The rupture has taken place in coarser HAZ region. Further in this current article, the mechanical properties and fracture analysis of the weld joints were correlated with weld metal microstructures.

Keywords: Titan-44, Beta-21S, Tensile properties, TIG welding process, EB welding process, Ti alloys, Microstructure.

Microstructure Characterization and Bonding Evaluation of Zirconium-Titanium Stainless Steel Trimetallic Clad Joints using Explosive Welding

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Cooler condensers have the stainless steel as tube side materials of the heat exchanger and carbon steel on the shell side of the heat exchanger. The tube side of the heat exchanger consists of tubes, tube sheets, channels shells and associated piping. The shell side of the heat exchanger consists of the main shell, bonnet shell assembly and the associated piping. The corrosion in nitric acid service is very severe for the tube side materials, where in the nitrous acids will be passing. Compared to shell side materials, the tube side materials have to be given utmost importance in selection so as to minimize the corrosion. Over a period of years, the SS 304L tubes have found to be corroded and pitting is observed on the tube surfaces, due to which the leakages were observed from the tubes and also from the tube-to-tube sheet joints. The problem of this pitting corrosion is reduced by using zirconium tubes instead of SS304L tubes, which have superior corrosion properties in nitric acid environment. If the tubes are to be replaced with zirconium, then the tube sheets are also to be replaced, which has a cost implication. The tube sheets used are 80 mm thick and 2500 mm diameter. Since the cost of zirconium is substantially high compared to SS 304L, the process of explosion bonding of zirconium with SS 304L tube sheets was carried out. In explosion bonding, the bond strength integrity and the material properties like metallurgical, physical and chemical are to be retained. In order to achieve the required bond strength, an inter-layer of titanium was

used between zirconium and SS 304L. The present work aimed to study on microstructure and mechanical properties of trimetallic zirconium-titanium-stainless steel (Zr-Ti-SS) clads made using explosive welding process. Zirconium was explosively clad on SS 304L steel over an inter-layer of titanium. Zirconium-titanium-stainless steel joint is produced during simultaneous cladding operation using a single cladding shot and plan parallel joining scheme. The clad interfaces were characterized by metallography, hardness and shear bond strength. The metallographic analysis of interfaces Zr/Ti and Ti/Steel structures and micro hardness measuring were performed. Mechanical testing of bond strength is performed on both interfaces by shear strength examinations.

Keywords: Cooler condensers, Heat exchangers, Tube-to-tube sheet, zirconium-titanium-stainless steel (Zr-Ti-SS) clads.

Design and Development of High Entropy Alloy Coatings for Orthopaedic Implants

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Humanity's search for new and advanced materials to fulfill their demands has played a crucial role in human evolution. High entropy alloys (HEAs) have garnered much scientific attention due to their superior properties compared to conventional alloys. They are a new class of metallic alloys that can give a synergistic effect in properties due to high configurational entropy. They are being explored for a wide range of applications. Bio HEAs (which generally include Ti, Ta, Hf, Zr, Nb) have been developed in recent times. Though these alloys show good biocompatibility under several conditions, they are challenging to commercialize because of the expensive rare earth elements and availability of inexpensive conventional alloys (316L SS and Ti-6Al-4V). Hence, designing an inexpensive alloy with good biocompatibility and mechanical properties can improve the metallic implant materials currently being used. In this work, novel HEAs $CrFeNiTiCu_x$ are being synthesized using vacuum arc melting. The primary components of the alloy are derived from 316L SS (Cr-Fe-Ni), and other elements are added for their biocompatibility (Ti) and antibacterial properties (Cu). The cast alloy is then characterized by x-ray diffraction, scanning electron microscopy, and energy dispersive spectroscopy to understand the formed phases. SA series of tests, including wettability, bio-corrosion, antibacterial, and cell viability, are performed to analyze the biocompatibility of HEAs. The Cu content is varied to optimise the the antibacterial effects and phase stability. The optimized composition is coated on 316L SS, and Tribocorrosion studies are performed to understand the stability of the coating.

Fabrication of Mg Porous Metal Structure through Vapor Phase dealloying

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Magnesium is one of the most abundantly available materials, and has outstanding strength-to-weight ratio with excellent mechanical and physical properties. So, it is quite suitable for numerous structural applications. Apart from its usage in structural applications, Mg is also a good candidate for bio-implants due to its biodegradability and non-toxic nature. Its applicability increases multifold when interconnected porous networks are introduced in its macroscopic structure. Introduction of pores adds two special properties like high specific surface area and high-curvature ligaments with different kinds of crystallographic facets. At present the most popular technique for fabricating various porous materials is the dealloying technique. Recently liquid metal dealloying (LMD) technique has been used to fabricate Mg porous structure and it was fabricated successfully along with a residual layer throughout the porous structure. The potential drawback for fabricating Mg porous structure with LMD is its inappropriate pore size and residue left over the porous structure after dealloying.
To address these drawbacks, a new technique called vapor phase dealloying (VPD) technique is developed, where the sacrificial element is removed by utilizing the vapor pressure difference between the alloy constituents during vacuum annealing (VA) process. So, we have explored this technique to fabricate the Mg porous structure by using Cd and Zn as sacrificial elements. After VA, pores are formed uniformly throughout the as dealloyed samples as compared to other conventional methods. We will also discuss the significance of metallurgical phases in VA process and their role to control the dealloying conditions in VPD technique. The current work will provide a pathway for designing new kinds of alloy systems to fabricate the porous structure where the vapor pressure difference between the constituent elements is few orders of magnitude.

Fe-Mn-Cu Alloy as a Novel Antibacterial Biodegradable Material

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Biodegradable materials are being widely investigated for internal fracture fixation devices in current years. Implants made of pure iron (Fe) provide good mechanical support but their lower degradation rate is a concern for temporary applications. Moreover, another clinically challenging complication associated with current degradable implant is bacterial infection. Once infection occurred, in worst case, may lead to failure of indwelling medical implant. In the past organic bactericidal material such as organic coating was developed to prevent the breeding of bacteria. However, the lack of antibacterial activity of the organic coating for a long period of time leads to development of inorganic antibacterial agents. In the past decade, copper (Cu) or silver (Ag) or rare earth elements has been added to medical implants and among these inorganic agents, addition of Cu attracted significant attention because of its ability to maintain healthy cellular activity. In this presentation, we will discuss about a new antibacterial Fe-Mn-Cu alloy. The hypothesis is that Cu beyond solubility in Fe-Mn, will enhance degradation rate by forming local galvanic cells. In this work, Fe-Mn (0-10 wt%) Cu alloys were prepared by powder metallurgy route. Six times increase in corrosion rate for Fe-Mn-10wt.% Cu alloy was observed compared to Fe-Mn alloy. Broth micro-dilution test showed increased antibacterial activity with Cu addition in Fe-Mn alloy while *in vitro* cytocompatibility study showed more than 70% cell viability for all alloys. Therefore, Cu alloying in Fe-Mn alloy has high potential to be used for internal fracture fixation devices with enhanced antibacterial activity.

Reference:

S. Mandal, R. Ummadi, M. Bose, V.K. Balla, M. Roy, Fe–Mn–Cu alloy as biodegradable material with enhanced antimicrobial properties, Materials Letters. 237 (2019) 323–327. https://doi.org/10.1016/j.matlet.2018.11.117

Laser Shock Peening of Nitinol at High Laser Power Densities and High Overlap Ratio

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The fatigue life of Nitinol is crucial for orthodontic and coronary stent applications. Improvement in fatigue life of Nitinol is being pursued in this study using a non-conventional surface engineering technique such as Laser shock peening. LSP over the years has been found to be capable of introducing surface compressive residual stresses leading to improved fatigue life in many a material. However, there are very few studies on LSP of Nitinol and the purpose of this study is to investigate its effect on residual stress and microstructural evolution in Nitinol. LSP at 7 and 9 GW/cm^2 laser power densities with a spot size of 0.8 mm and 90 % overlap ratio resulted in a tensile residual stress state although the starting material had a compressive residual stress state. The generation of tensile residual stress is attributed to the high laser power densities and overlap ratios adopted in this study. Interestingly the LSPed material provided contrasting surface hardness with Nitinol LSPed at 7 GW showing higher and material LSPed at 9 GW showing lower surface hardness compared to the as-received material. This contrasting behavior is attributed to the competing effects of cold working and thermal effects during material-laser interaction. Furthermore, we investigated the effect of LSP on the transformation temperatures (M_s, M_f, A_s, A_f) in Nitinol using differential scanning calorimetry and did not observe any significant changes. However, during cooling the enthalpy of phase transformation (A→M) is found to be affected due to LSP.

Fabrication and Characterization of Mg-Ca Biodegradable Alloy by Powder Metallurgy

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Owing to the natural degradability, good biocompatibility and favorable mechanical properties, magnesium (Mg) and its alloys are gaining attention to serve as implants for load-bearing applications in the medical industry. They exhibit similar Young's modulus (41 - 45 GPa) to that of human bone (10-30 GPa), which can reduce stress shielding during load transfer at the bone-implant interface. Despite this, their use as biomedical implants is limited due to their poor

corrosion resistance and the consequential mechanical integrity problems. Further Mg and its alloys are susceptible to suffer attacks in chloride containing solutions, e.g. the human body fluid or blood plasma. Thus, alloying with other metal elements is the most effective tool to improve the mechanical properties and corrosion resistance of Mg. Among the other alloying element calcium is found more useful for bio-applications, as being main composition in human bone, showed a great performance in improving bone healing process, and having low density just like magnesium.
In the present work binary Mg-Ca alloys with varying calcium content were fabricated using mechanical alloying (MA) followed by the hot consolidation process. The effect of calcium content on mechanical, corrosion and biodegradable properties was studied. The alloy was prepared by mechanical alloying Mg and Ca with varying Ca wt.% from 1 to 5 under an argon atmosphere using 2 % polyvinyl alcohol as a process control agent to avoid excessive cold welding of the powder. The bulk sample was prepared by hot consolidation of the alloyed powder and the samples were used for microstructure, mechanical and corrosion property evaluation. The results showed that increasing Ca content decreased grain size (from 80 μm to 5 μm) led to improved hardness values (from 30 HV to 82 HV) and also higher Ca content led to an increase in the amount of Mg_2Ca phase at grain boundaries resulted in higher corrosion rates. It can be concluded that although increased Ca content improved the mechanical properties of the alloy, it does not satisfy the corrosion resistance criteria required for bone healing.

Keywords: Biodegradability, Corrosion, Microstructure, Hardness.

Effect of Heat Treatment Temperatures on the Microstructure and Mechanical Properties of Lithium Disilicate Glass Ceramics in Dental Restorations

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Lithium Disilicate Glass Ceramic is primarily used for dental applications. The SiO_2-Li_2O-Al_2O_3-ZrO_2-P_2O_5 based dental glass ceramic with additives were synthesized by glass ceramic route. SiO_2 & Li_2O were the main components of the system. The additives comprised of P_2O_5 as nucleating agent, CeO_2 as glass coloring oxide, ZrO_2 as coloring body, La_2O_3 and Al_2O_3 both used to avoid reaction with the investment material. The other additives used were K_2O to lower the viscosity and reduce the processing temperature and MgO for better pressing ability. The route comprised

of milling, glass melting and followed by quenching to get glass frit, regrinding of frit to form fine powder of size ~2μm and compaction. The pellets so formed were subsequently annealed at 500 °C/hr followed by first heating at 530 °C and second heating at 750 °C – 950 °C/2 hrs. Density ranged from 2.34-2.43 g/cm^3. Characterization for XRD revealed Li-Metasilicate glass formation after first heating and Li-Disilicate glass ceramic formed during second heating. SEM of Li-Metasilicate revealed the microstructure comprising of small spherical crystals, whereas Li-Disilicate showed needle / plate like crystals of length 1 μm – 4 μm. Wear rate ranged from 0.0100 - 0.02311 mm^3/m for 5N & 0.01265 – 0.02243 mm^3/m for 25N. Microhardness ranged from 350 – 440 HV & the pellets passed the standard chemical solubility test with the values ranging from 110 – 320 μg/cm^2.

Keywords: Lithium Disilicate, Glass Ceramic, Microstructure, Wear Rate, Lithium Metasilicate.

POSTER PRESENTATIONS

Thermal Expansion Studies of TiTaNbMoZr Refractory High Entropy Alloy

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Refractory high-entropy alloys (RHEAs) have been proposed as candidates for high temperature structural applications owing to their high temperature strength, long-term phase stability, high temperature oxidation resistance etc. TiTaNbMoZr RHEA was melted by vacuum arc melting unit. Thermal expansion behaviour of as-cast TiTaNbMoZr RHEA was studied by in-situ synchrotron XRD (SXRD) and dilatometry in the temperature range 298-1273 K. TiTaNbMoZr RHEA exhibits two solid solution phases with BCC structure at room temperature. The predominant phase is named as B-major and the minor phase is named as B-minor. B-major phase and B-minor phases are found to exist until 1273 K and 1173 K, respectively. Above 1173 K, a new phase (B¢) is formed. Temperature dependant lattice parameters (a_T)for B-major, B-minor and B¢ phases are calculated. The coefficient of thermal expansion ($CTE_{lattice}$) as a function of temperature is calculated from *a* vs T curve for B-major and B-minor phases. The effective $CTE_{lattice}$ (a_l^m) of the TiTaNbMoZr RHEA is calculated in te temperature range 298-1173 K and found to increase linearly with temperature in the range (8.1-8.6) ´ 10^{-6} K^{-1}. Bulk coefficient of thermal expansion (CTE_{bulk}) (a_{dil}^m) of TiTaNbMoZr RHEA is calculated from dilatometric strain (dl/l_0). For TiTaNbMoZr RHEA, a_{dil}^m varies in the range (7.5-10.9) ´ 10^{-6} K^{-1}. Dilatometric strain and lattice strain are compared. It is observed that both are identical up to 1000 K and beyond 1000 K, the dilatometric strain increases significantly due to the generation of thermal vacancies.

Effect of Alloying Addition on Evolution of Recrystallization Texture in a Face Centered Cubic Material

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Despite enormous amount of research in the field of recrystallization, there is still requirement of better understanding which deals with the evolution of micro-structure and texture of various kind of materials. Very few materials can be used for industrial application in its pure form. So, effect of alloying addition on the final microstructure and texture development after annealing has gained a great importance. Different alloying elements affect the properties of the system in different ways. Like addition of some elements may decrease the stacking fault energy (SFE) of the system and some changes the deformation behavior without altering the SFE. As an example, Ni is a high SFE material and addition of Co decrease the SFE of system while addition of Fe does not change its SFE, yet it changes its deformation behavior. The present work is aimed to develop a comprehensive understanding of the effect of alloying addition which does not alter the stacking fault energy of the system, on the recrystallized microstructure and micro-texture evolution. Different kinds of deformation heterogeneities such as deformation bands, micro-bands, shear bands, deformation twins, etc. play a vital role during the initial stage of recrystallization and texture development henceforth.

Ni-Fe alloys were chosen for this study which is the most ideal system for this study. Ni-Fe alloys with different Fe content (0, 20, 40 Wt.%) were rolled to 70% reduction in thickness and subsequently annealed above recrystallization temperature. Textures were measured by SEM-EBSD and X-ray diffraction. It was found that there is always a trace of the orientation of new strain free grain in deformed structure and annealing twins play a vital role in the evolution of recrystallization texture. A detailed micro-mechanism of annealing microstructure and texture formation will be presented.

Role of Carbide in Mitigation of Hydrogen Embrittlement

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The study dealt the role of carbide as hydrogen traps in mitigating the hydrogen embrittlement. Three carbide systems have chosen in the present study. Though carbides are efficient hydrogen traps, role of dislocation as traps and combined effect of both still needs to explore. Also, the proposed embrittlement mechanisms, based on assumption that, accumulation of hydrogen in traps could result in internal pressurization and crack initiation at high stress concentration zones, are still at variance. It is thus, in view of development of alloys with different chemical composition and microstructure, and the complexities associated with hydrogen related degradation mechanisms, an investigation has been made to understand the mode of transport and accumulation of hydrogen at different traps with the help of advanced characterization techniques.

Keywords: Hydrogen Embrittlement, Carbides, Dislocations, Traps

Hydrogen Embrittlement of In-RAFM Steel Studied by In-Situ Tension Testing with Electrochemical Charging

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RAFM steels have been developed to serve as the structural components of test blanket module (TBM) of ITER fusion reactor. One of the main issues in the application of candidate materials for TBM structural is their exposure to hydrogen from transmutation reaction (n-p) and external sources such as water and helium gas used for cooling. Hydrogen embrittlement (HE) is a complex phenomenon involving a number of parameters such as microstructure, temperature, loading mechanism and hydrogen interaction means. These variables influence differently to the phenomenon in a diverse fashion. For inferring meaningful insights about hydrogen embrittlement (HE), one of the prevalent means is undertake mechanical testing with in-situ cathodic charging. The current work is to study manifestation of HE in an India-specific RAFM steel, designated for application in fabrication of test blanket module (TBM) for ITER. For this purpose, in-situ tensile experiments under hydrogen introduction by cathodic charging have been carried out over a range of current density (~0.1-4 A/cm^2). In contrast with un-hydrogenated material, cathodic charging results in substantial reduction in both strength and ductility. However, further rise in current density resulted in additional lowering in ductility with slight hardening. To explain the trends,

fractographic studies along with EBSD have been carried out. Exposition of the observed HE findings has been critically discussed in light of current acquaintance.

A Comparative Study of Si_3N_4-Mo-Si Cermet Fabricated by Conventional Sintering in Argon and Hydrogen Atmosphere and Spark Plasma Sintering

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Silicon nitride (Si_3N_4) is well known for its application as a structural material and high-temperature applications due to its refractory nature. Apart from this, its chemical stability, low density, high hardness, high-temperature oxidation resistance makes it a candidate for versatile applications like bearing, cutting tool and engine components. Despite attractive properties, Si_3N_4 (being a ceramic) has some limitations due to its brittle nature. In the recent study, an effort is made to prepare the Si_3N_4-Mo-Si cermet, reinforced with Y_2O_3 and Al_2O_3 as sintering additives (5 wt. % and 10 wt. % respectively), by powder metallurgy to improve the ductility and densification of pure Si_3N_4. These cermets are consolidated by conventional sintering using argon and hydrogen atmosphere and spark plasma sintering. The effects of the gaseous environments during conventional sintering on the cermets' physical, mechanical, and tribological properties are investigated. It is observed that the hydrogen environment has a more positive impact on the properties of the cermet than the argon environment. The values of relative density, Vickers micro-hardness and indentation fracture toughness for hydrogen environment are 72.76 %, 7.76 ± 1.97 GPa and 9.02 ± 0.52 MPa.$m^{1/2}$, respectively. The spark plasma sintered specimens are found to have the best and optimal properties and have shown the best results among all three consolidation techniques. The relative density, Vickers micro-hardness, and indentation fracture toughness of spark plasma sintered sample are found to be 96.66%, 15.72 ± 1.56 GPa, and 11.12 ± 1.34 MPa.$m^{1/2}$, respectively. At the same time, the wear rate at 20 N loading with a 2508 m sliding distance is found to be 0.12×10^{-3} mm^3/m with a mass loss of 0.001g. The results have been correlated with the phase evolution and microstructural analysis.

Investigation of Thermal Stability and Mechanical Properties of $Al_{0.2}CoCrFeNiMo_{0.5}$ High Entropy Alloy

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High Entropy Alloys (HEAs) attracting the present research because of their superior structural and physical properties compared to conventional alloys. The present work focuses on the thermal stability, microstructure evolution and mechanical behavior of $Al_{0.2}CoCrFeNiMo_{0.5}$ wrought high entropy alloy, processed through induction melting followed by hot forging and thermomechanical processing. Homogenization treatment done at 1200°C 6 hr followed by cold rolled up to 80% reduction in thickness. Cold Rolled (CR) samples were annealed at 1000 °C for different time intervals in the range of 1 to 60 hr followed by water quenching. Microstructural evolution during annealing were studied using FE-SEM, EBSD and mechanical properties were studies by performing hardness and tensile experiments. The present HEA showed very sluggish grain growth. However, there is a moderate coarsening of the secondary phase and precipitates were observed with annealing time. The drop in hardness with annealing tim e is very minimal even after annealing at 1000C for 60 hr. Furthermore, the tensile experiments on the sample annealed at 1000 °C for 1 and 60 hr revealed that there is a twice increase in the plastic ductility from 1 hr to 60 hr without significant drop in the ultimate tensile strength. The probable reasons will be discussed with proper justifications.

Keywords: High entropy alloy, aging treatment, grain growth, microstructure, tensile test

Thermal Stability of Mechanically Milled Silicon: Effect of solute addition

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This work aims at studying the thermal stability of the nanocrystalline silicon, with a long-term objective of employing nanocrystalline silicon for structural applications. Nanocrystalline materials on account of the large fraction of grain boundaries are thermally unstable with the

material system trying to reduce its free energy through grain growth. Hence solute segregation at the grain boundaries is employed for reducing the grain boundary energy and thus enhance the stability of nanocrystalline materials. To identify the appropriate solute for silicon, the Darling et al. model is adopted and this model suggested Boron as a potential element for stabilizing the nanostructure. Ball milling of Si and Si-4 at. % B was carried out for 7 hours each to produce milled powders bearing crystallite size approximately 11 nm in size. The thermal stability of these powders was studied using the differential scanning calorimetry through calorimetric scans running from 300 K till 1473 K at scan rates of 20, 30 and 40 K/min. The activation energies of structural transitions were determined using Kissinger's analysis and the same was found to be e 232, 52, and 310 kJ/mol for 7 h ball milled silicon and 374, 122, and 994 kJ/mol for 7 h ball milled Si + 4 at. % B for for their respective peaks. These and other results obtained from this work will be presented.

Study of Nanomechanical Properties of P9 Ferritic/Martensitic Steel

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In the present study, the 9Cr-1Mo ferritic martensitic (P9) steel was subjected to different heat treatments, namely austenitization followed by water quenching (WQ), normalizing (N), furnace cooling (FC), and subsequently tempering. Detailed microstructural characterization was carried out on the heat-treated steels to obtain quantitative information of microstructural parameters like lath width, size, volume fraction, and number density of the precipitates. Instrumented indentation tests (IIT) were carried out at room temperature with a spherical indenter for evaluating hardness and elastic modulus. Yield strength of the steel subjected to the above treatments were evaluated from the stress-strain curves derived from the load versus displacement curves using neural networking method and yield parameter calculations through cyclic indentation tests. Nanomechanical properties like hardness and yield strength were compared and validated with microhardness and tensile test results. Variation of yield strength of the steel due to change in cooling rate and after tempering were correlated to the microstructural changes. Details of the study will be presented in the conference.

Characterization of ZnO Nano Wire: A Microstructural Perspective

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The superior performance of metal oxide nanowires finds extensive engineering applications. ZnO belongs to such category. ZnO wires are formed through chemical vapor deposition (CVD) route. The galvanized steel plate was used as base. The careful electron microscopy studies on these nanowires reveal that, the wires have the uniform morphology. The ongoing investigation aimed to look the structure-property correlation of the nanowires formed at different processing duration.

Keywords: Metal oxide, ZnO nanowire, Electron microscopy

Development of high entropy alloy by using sequential Alloying

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The most used thermal barrier coatings for high temperature application which are applied on superalloys are Yttrium-stabilized zirconia (YSZ) coating. Recently an alternative interest in high entropy alloys consisting of iron, cobalt, nickel, chromium, copper, and silicon with intermetallic compounds of NiAl and Ni3Al is increasing for the thermal barrier application due to their comparable properties at high temperature. The major drawbacks of these high entropy alloys are higher thermal conductivity and their softening at high temperatures. If these drawbacks are overcome, then these alloys can replace Yttrium-stabilized zirconia (YSZ) coating. In this project it is decided to synthesise the high entropy alloy by sequential alloying using high energy planetary ball mill. Two types of nickel powders were used namely - as received and high pressure torsioned (HPT) for alloying in ball milling as well as for synthesis of intermetallic compounds. The powders were analysed by XRD to determine phases present. It has been observed that by using high pressure torsion process milling time has reduced significantly with improved homogeneity. Thermal conductivity measurement was performed.

Influence of Warm Forging on Mechanical and Microstructural Properties of 316L Steel

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The warm deformed microstructure of 316L ASS has been investigated through the usage of EBSD-SEM. An attempt has been made to recognize the impact of deformation and hat treatment on the mechanical and micro structural properties of 316L stainless steel. From micrograph it discovered that grain refinement occurs after warm forging of sample, refinementof microstructure takes place because revision occurs from alpha ferrite and martensite into austenite that's shaped after warm deformation. Solution annealed sample after warm forging offers higher mechanical energy due to conversion of homogenised and equaixed grains of austenite. From experimental result it is observed that hardness increases after growing the percentage of forging however impact energy decreases after growing the percentage of forging. The size of grain reduced after deformation, but homogeneous distribution of grains was obtained after solution annealing of 50 % deformed sample. Solution annealing after 50 % deformation gives optimum impact strength and hardness therefor from experimental results, we conclude that solution annealing after deformation produces homogeneous microstructure which gives optimum strength after deformation.

Keywords: Annealing, Deformation, EBSD, Microstructure

Breakdown Reduction at NTM with Bullet Proofing

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No Twist Mill (NTM) of New Bar Mill is a combination of 6 finishing stands which gives rebars their final cross-section and shape with branding and ribs. Due to very high speed of rolling (>33m/s) at 1100 ^{o}C with 10 mm rebars cross-section & huge waters splash used for roll cooling, NTM becomes very critical part in terms of safety & breakdown. So, while rolling NTM is fully covered with strong metallic inspection cover. But metallic cover made it impossible to observe

the behavior of rebars inside NTM making us clueless when there are lot of breakdowns leading to huge delay and loss.
So, to get the visibility of rolling inside NTM in running condition, many solutions were thought of like installation of camera inside the NTM inspection cover. But the camera couldn't sustain due to huge water splash and high temperature around 1100 ^{o}C. It was then thought to replace the NTM inspection cover from metallic to transparent material but no such material was available in our knowledge which can withstand such high temperature and at the same time to be strong enough to not to allow material to come out during cobble.
Finally, an idea struck to the mind when transparent bulletproof glass windows were being installed at banks. So, we provided for inspection holes made up of bullet proof glasses frame in the existing metallic inspection covers in both the lines which not only provide better visibility and safety but also are detachable from outside for cleaning and maintenance. Thus, analysis of behavior of rebar inside NTM is easily visible.

Keywords: No Twist Mill, rebar, bullet proof glass, New Bar Mill, temperature

Microstructural Characterization of Armour Steel After Ballistic Test

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The superior impact toughness and ultimate tensile strength finds various applications of armour steel. The microstructure with nano-scale martensite laths. A 6 mm hot rolled sheet of amour steel was subjected to ballistic test. Two different set of experiments were done. One with firing the bullets within the damage zone of previously fired bullet and second away to the damaged area. A clear distinct morphology in adiabatic shear bands was observed. The present investigation generated the useful data of through thickness gradients of stress, dislocation and texture. This study would help in predicting the microstructural response and damage criterion.

Keywords: Armour steel, Nano-martensite lath, Ballistic test, Adiabatic shear bands

On the reproducibility of cell structure and mechanical properties of Al-Si- Mg/SiCP foams in relation to the foaming temperature

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The scatter in the structure and properties of melt processed aluminium based foams is a matter of concern when implementing the manufacturing process commercially. This is addressed in this work by foaming experiments on a pre-made A359-20% SiCP composite through melt-processing using titanium hydride (TiH2). With 0.75 wt. % of TiH2, two foaming temperatures (640 °C and 660 °C) were chosen. At each temperature, three identical experiments were carried out to check the reproducibility in foam structure and properties. It is observed that foams made at 640 °C were reproducible in terms of foam expansions, cell size, density, modulus, and compressive properties. However, foams prepared at 660 °C were not reproducible due to fundamental instability of liquid foam. The collapse of liquid foam during solidification resulted in elongated cell structures within the solidified foam ingot. But for this collapse at 660 °C, good quality could be achieved at both the foaming temperatures in terms of isolated cells without cell wall ruptures, cracks, or abnormal cells. Also, cell size distributions, and properties in undistorted regions in 660 °C-foam ingots are comparable to those obtained in 640 °C-foams. Overall, good cell structures and mechanical properties could be obtained in these melt-processed foams on a reproducible basis.

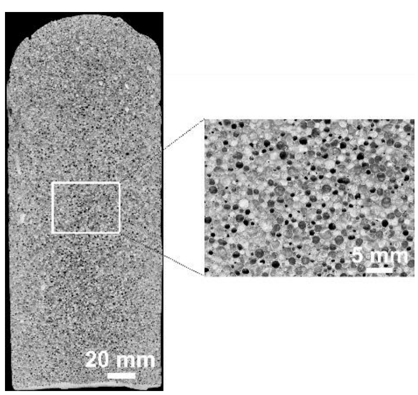

Fig. 1. A359-SiC foam prepared at 640 °C

Keywords: Al foam; Al-SiC composite; closed cell foam; compression

Lanthanum Zircoante Thermal Barrier Coatings and Aircraft Materials: The Present and The Innovations

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Thermal Barrier Coatings (TBCs) are protective ceramic insulating coatings (100 µm to 1 mm thick), placed on aero- and land-based gas turbines to protect the engine from harsh high temperature service environment, to reduce thermal fatigue, thereby increasing the component life and overall efficiency. They are applied via (a) electron beam physical vapour deposition (EBPVD) or (b) atmospheric plasma spraying (APS), based on cost and performance criticality. APS employs plasma sprayable TBC material/powder to flow through a high temperature plasma (@>10,000°C), accelerating within it to mildly soften and to impinge on the prepared substrate surface to form the coating. 6 to 8% Yttria Stabilised Zirconia (8YSZ) are the most researched and accepted as state-of-the-art gas turbine TBCs. Its constraints include structural phase destabilisation, microstructural instabilities and thermal instability above 1100 °C, resulting in high thermal induced stresses, spallation and reduced lifetime. Pyrochlore structured $A_2B_2O_7$ has become the most promising alternative TBC material being researched for next generation advanced gas turbines offering phase stability up to >2000 °C, high sintering resistance and low thermal conductivities, Here, A is the rare earth element (Gd, Y, La, Sm, or Dy), and B is Zr (transition or post-transition metal with a changeable oxidation state). This study focuses on lab synthesised Lanthanum Zirconate (LZ) pyrochlore TBCs, plasma sprayed on Inconel 718 plates, thermal fatigue tested and analysed for structural phase (XRD) and microstructure (SEM), Results were compared with identically tested commercial 8YSZ TBCs. LZ withstood almost twice the number of thermal fatigue cycles compared to 8YSZ at 1200 °C. The results are detailed in the paper.

The primary materials presently being used in aircraft manufacturing and the related general information from published literature has been reviewed and included in the paper. The recent innovations in this sophisticated field of engineering are also highlighted.

Comparative Study of Tribological Properties of Al7075 Hybrid Composites

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Al 7075 alloy is widely used in aerospace and automobile industries due to the ultrahigh strength with low density. The samples were synthesized by the powder metallurgy route. Powder metallurgy route has the great advantage over the stir casting process, that it gives uniform mixture of the alloy powder and the reinforcement powder with different sizes. The results are taken out by characterization tools. Two different types of Hybrid Matrix Composites consist of 10 wt % B4C and solid lubricants such as Gr with (1,3,5%) and MoS2 (1,3,5%) were sintered in the Hot Press Sintering machine for the 6 min at 550 ^{0}C, 40 MPa. Dry sliding wear test were carried out at the 10 N, 40 N load for 2.5 m/s speed. From the above Hybrid Matrix Composite the 3% Graphite and the 3% MoS_2 considerably reduces the wear rate (1.34×10^{-3} mm^3/m and 0.23×10^{-3} mm^3/m). Worn out surface and subsurface analysis was carried out by using Scanning Electron Microscopy.

Deformation Processing Map of Magnesium Metal Matrix Composites containing Polymer derived SiCNO Particles

Krishnamoorthi J., Nagaraj M Chelliah

Deformation processing map has been widely used in metal forming industries to optimize the processing parameters such as the working temperature and the applied strain rate. The present work aims at understanding the hot deformation behavior of Mg-based metal matrix composites by using deformation processing map. Mg-based composites were fabricated by injecting liquid polysilazane precursor into molten magnesium via in-situ pyrolysis. As-cast composites were subjected to un-axial hot compression testing in a temperature range of 150-350 ^{o}C and in the strain rate range of 10^{-3} to 1 s^{-1}. Deformation processing map was constructed in accordance with dynamic materials model. The efficiency of the power dissipation of as-cast composites was obtained as function of temperature and strain rate. Microstructural characterization revealed that while adiabatic shear banding occurs at low temperature (150-200 ^{o}C) and high strain rate of 1 s^{-1}, dynamic recrystallization evolves at high temperature (350 ^{o}C) and low strain rate of 1×10^{-3} s^{-1}. The workability and instability domain of the as-cast composites were discussed based on the efficiency of power dissipation during hot compression.

Nanomechanical and Electrical Characterization of PMMA/ZnO Nanocomposite Films for Applications in Energy-scavenging Microsystems

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Piezoelectric nanocomposite films, consisting of poly-methyl methacrylate (PMMA) as matrix and zinc oxide (ZnO) nanoparticles as reinforcement, are potential candidates for materials to be used as structural and functional components of microdevices that can scavenge energy from ambient mechanical vibrations. The design of such energy-scavenging micro/nano-systems will require knowledge of the process-microstructure-property relationships of nanocomposites films. In this study, PMMA/ZnO nanocomposite films were synthesized using ultrasonic probe sonication and solution-casting. The nanomechanical characterization of the nanocomposite films was conducted using a nanoindenter, via quasi-static mode and via dynamic mode. The electrical characterization involved measuring the dielectric constants and electrical conductivity via frequency-dependent impedance measurements of the nanocomposites using an impedance analyzer. Mechanical-to-electrical energy conversion characteristics of the composites were evaluated by measuring short-circuit current and open-circuit voltage generation under cyclic mechanical loading. In addition, scanning electron microscopy of the nanocomposite thin films was performed to get an insight into the variation of the material properties as a function of ZnO content. Results indicate that the highest indentation modulus and the highest indentation hardness are exhibited by 5 wt.% ZnO nanocomposites. Storage modulus, loss modulus, and loss-factor obtained via nanoindenter based dynamic mechanical analysis (nanoDMA) indicate that the PMMA/ZnO nanocomposites exhibit viscoelastic behavior in the frequency range of 10 Hz to 201.5 Hz. The dielectric constant (εrεr) increases with ZnO content at a frequency of 20 Hz. However, the values of εrεr decreases monotonically as the frequency is increased from 20 Hz to 200 Hz. The electrical conductivity of the nanocomposites was found to increase with increasing ZnO content as well as with increasing frequency. The maximum peak current and voltage output of 5 wt% ZnO nanocomposites were found to be ~2.4 nA and ~2.7 V, respectively, under the mechanical force of 2.58±0.01, 2.58±0.01 N.

Stress Corrosion Cracking Studies on Selective Laser Melted M300 Maraging Steel

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Additive manufacturing (AM) has shown promise to manufacture complex and near net shaped products for the space industry. AM alloys show micro-structural anisotropy along various directions due to the unique layer by layer melting and deposition of metallic powders by lasers. Maraging steels are being extensively used in the aerospace industry due its high strength and fracture toughness. One of the major challenges that Maraging steels faces is the susceptiblity to stress corrosion cracking. In the present study corrosion and stress corrosion cracking (SCC) tests have been carried on selective laser melted M300 maraging steel. Effect of microstructure on the SCC index of selective laser melted M300 is compared with wrought M300 margaging steel. Corrosion behaviour was studied using potentiodynamic polarisation and electrochemical Impedance spectrocopy in 3.5 wt. % NaCl solution. Anisotropy of properties were evaluated in X and Z directions. Slow Strain Rate tests have been carried out in air and 3.5 wt% NaCl to evaluate the SCC index of maraging steels. Mechanism of fracture is studied by fractography using Scanning Electron Microscope.

Experimental Determination Defects Kinetics in β-NiAl (Pt) alloy systems

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Intermetallic alloys with the B2 crystal structure have been a popular choice for structural applications because of their good thermal and mechanical properties that can be retained at high temperatures. These alloys, specifically β- NiAl alloys, are generally used as an interlayer between thermal barrier coating (TBS) and Ni-based superalloys in hot parts of aero-gas turbine engines. The addition of Pt to β-NiAl leads to an increased life span of the bond coats. Atomic diffusion plays a major role in deciding the stability of the off stoichiometric bond coats. The enhanced atomic diffusion in non-stoichiometric NiAl has been attributed to the presence of point defects. Hence, a clear understanding of the Kinetics of point defects will lead to an appropriate alloy design for high-temperature structural applications. However, the lack of vigorous experimental data on the direct measurement of vacancy formation energy of these alloys systems is still in a

hurdle. This presentation focusses on experimental determination of the formation energy of vacancies in various off-stoichiometric β-NiAl and β-(Ni, Pt)Al alloys from various quenching temperatures via a specially designed residual resistivity experimental setup.

Studies on Microstructure and Microhardness of Laser Surface Alloyed CeO_2 Dispersed Surface of Inconel 718

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The present work concerns understanding the effect of laser surface alloyed CeO_2 dispersed Al on the hardness of INCONEL718. Laser surface alloying has been carried out using a 800 W diode laser. The microstructure and microhardness of the alloyed zone were analysed by scanning electron microscope and Vicker's microhardness testing machine, respectively. The microstructure of the alloyed zone is defect-free, and homogeneous with a continuous solid-liquid interface. There is dispersion of CeO_2 in INCONEL 718 matrix consisting of γ/γ' and β phase. Appropriate amount of rare earth (CeO_2) improves the hardness of the surface significantly. The microhardness value decreases from top surface to interface zone.

Corrosion and wear analysis of heat-treated nitrogen martensitic steel

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High nitrogen martensitic steel (HNMS) was solutionized at 1050 °C and 1075 °C, followed by tempering at 180, 350, 525 °C. Corrosion behaviour was studied with electrochemical analysis using three-electrode methods in 3.5% NaCl electrolyte solution. Analysis was made using polarization curves taken at different austenitizing-tempering combinations. Results showed that the value of corrosion current hence the corrosion rate, increases with an increase in tempering

temperature, which has been attributed mainly to the depleting Cr concentration in the matrix with tempering. This is clear from the presence of coarser intermetallic carbides ($M_{23}C_6$ type) at higher tempering temperatures. Qualitative analysis was carried out on the samples austenitized and tempered by keeping them under a corrosive environment for 96hrs. Samples were imaged to observe the amount of pitting corrosion taken place on the surface. At higher austenitizing temperature, the Cr rich precipitates dissolve in the matrix, enhancing the overall Cr content. This promotes the thickening of Cr_2O_3 passive film and enriches Cr^{3+}. Nitrogen content in the matrix also increases with increasing austenitizing temperature, enhancing the stability of the passive film and hindering pit initiation in a corrosive environment. Furthermore, preliminary wear test analysis using pin and disc setup was carried on the samples prepared after each heat treatment cycle, which showed the minimum wearing at lower tempering temperature. Finally, a heat treatment cycle has been proposed to obtain the optimum corrosion and wear resistance.

Keywords: Nitrogen-martensitic stainless steel, heat-treatment, tempering, corrosion, wear resistance

Zinc-Calcium Phosphate Conversion Coating on AZ31 Magnesium Alloy for Automotive Application: Study of Zn^{2+} and Inhibitor (NaF) Concentration

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Magnesium and its alloys exhibit some excellent mechanical and physical properties such as low density, high strength to weight ratio, biocompatibility, excellent castability, machinability, and weldability. They find applications in various industries ranging from automotive, aerospace, electronics, medical, and many more. However, compared to other engineering structural materials, magnesium is highly electrochemically active, and it does not form a stable oxide layer on its substrate, unlike aluminum (Al) or titanium (Ti). One of the significant challenges associated with magnesium and its alloys is that they are highly susceptible to corrosion, thus limiting their widespread potential applications. Several methods such as chemical conversion coating, electroplating, anodizing, organic coating, hybrid coating, electroless coating, and vapor phase processes are used to coat the magnesium substrate to overcome these challenges. Out of these,

chemical conversion coating is the most economical, simple, and widely used in industries to counter the problem associated with corrosion of Mg substrate. Different types of conversion coating techniques such as chromium conversion coating, phosphate conversion coating (Zn-P, Ca-P, Mg-P), rare earth, stannate, and vanadium-based conversion coatings are used for coating magnesium to prevent corrosion. Chromium-based conversion coating produces harmful hexavalent chromium ions (Cr^{6+}), which is carcinogenic, and its use is prohibited in most European nations. Thus, this work focuses on developing chromium-free and environment-friendly chemical conversion coatings for automotive application on AZ31 magnesium alloy using zinc-calcium phosphate conversion coating (Zn-Ca PCC). In this study, different Zn-Ca PCC compositions baths were formulated, and the effect of increase in the concentration of Zn^{2+} and the inhibitor (NaF) were investigated for understanding the coating corrosion performance. The corrosion resistance of coated samples was examined using electrochemical tools such as Electrochemical Impedance Spectroscopy (EIS) and Linear Polarization. Techniques such as Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) were used to understand the morphology & compositions of the coated specimens.

Electro Catalytic Coatings for Hydrogen Evolution Reaction

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Electrocatalytic material was synthesized and characterized for hydrogen evolution reaction. Firstly, porous copper was electrodeposited over flat copper disc using hydrogen bubble dynamic template. It was electrodeposited using pulsed current at peak current density 490 mA/cm^2, duty cycle 80% for 90 seconds. The electrolyte having 0.25 M $CuSO_4$ and 0.75 M H_2SO_4 and at temperature 25 ^{0}C was utilized for electrodeposition. Secondly, nickel was electrodeposited over porous copper utilizing electrolyte 0.1 M $NiCl_2.6H_20$ and 2 M NH_4Cl maintained at temperature 25 ^{o}C and at different overpotentials from 300 mV to 1000 mV.
The electrocatalysts were characterized for determining electrochemically active true surface area using electrochemical impedance spectroscopy in 1 M KOH solution at 25 ^{o}C. The kinetic parameters for hydrogen evolution reaction were calculated from Tafel polarization and electrochemical impedance spectroscopy in 1 M KOH at 25 ^{o}C. Surface morphology was characterized used scanning electron microscopy.
Key quantitative results here SEM analysis, it was seen that during Ni coating on porous copper, the needle-like microstructure of Cu Foam was become cauliflower-like microstructure and becomes denser.

Mechanical and Tribological Behavior of Nitride (binary and tertiary) Ceramic and Alloys for Versatile Engineering Applications

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Nitride material is versatile in nature and used for improving abrasion, wear, hardness, fracture toughness of the matrix or the surface of the component. These materials could be either binary or tertiary compound with examples encompassing Si_3N_4, BN, TiN, MoN, AlN, VN, TiAlN, TiVN, TiMoN, $Cr_{1-x}Al_xN$ and composites based on above mentioned compounds. Different synthesis processes like hot pressing, ion beam deposition, sputtering, high energy milling, high temperature sintering are generally carried for synthesizing different nitride based material depending on the application front. Synthesis procedures are needed to be optimized for proper evolution of phase and for fabrication over the material matrix. Various characterizations like hardness, wear and surface profilometry analysis, morphological features, indentation analysis, chemical analysis are required depending on the area of application regime of the material. Stress is given on particular analysis depending on application types and industries concerned. Nitride materials act as both coating and substrate depending on the criteria of applications. In recent times, this group of material have extended its application domain to biomaterial applications in addition to semiconductor industries, automotive components, cutting tools, aerospace and gas-turbine applications.

Keywords: Nitride, wear, hardness, tribology, morphology

Finite Element Analysis of Mechanical and Microstructural Properties of Additively Manufactured 17-4 PH Stainless Steel using SLM

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Additive manufacturing (AM) is a novel manufacturing method which provides more freedom in design, manufacturing near net shaped parts as per demand, lower cost of production and expedition in delivery time to market. Among various metals AM techniques, Laser Powder Bed Fusion (L-PBF) is the most prominent one that provides higher accuracy and powder proficiency in comparison to other methods [1]. Particularly, 17-4 PH alloy is a martensitic precipitation hardened (PH) stainless steel characterized by resistance to corrosion up to 300 °C and tailorable strengthening by copper precipitates. Additively manufactured 17-4 PH stainless steel exhibited a dendritic/cellular solidification microstructure in the as-built condition. It is widely used as a structural material in marine environments, power plants, aerospace and chemical industries. The excellent weldability of 17-4 PH stainless steel and its ability to be heat treated to improve mechanical properties make it a good material choice for L-PBF [2]. In this study, the microstructures of martensitic stainless steels in the as-built state, as well as the effects of process parameters, building atmosphere, and heat treatments on the microstructures, are reviewed. Mechanical properties of fabricated parts are studied through micro-hardness and tensile tests. Tensile tests are carried out under different strain rate at room temperature. In addition, the effect of process parameters and heat treatment conditions on mechanical properties are critically reviewed. These studies revealed the performance of L-PBF fabricated 17–4 PH stainless-steel parts under cyclic loading, and the results indicated that fatigue properties were more sensitive to the defects generated by L-PBF (e.g., porosity, microcracks), leading to the low fracture strains and stresses under cyclic loading. Rapid melting, solidification, and re-melting of powders during the process and different combinations of processing parameters result in a complex thermal history and heterogeneous microstructure [3] and necessary to better control the microstructures and properties of L-PBF PH stainless steels through high-efficiency and low-cost heat treatments.

Keywords: 17–4 PH stainless steel, laser powder bed fusion, selective laser melting, microstructure, additive manufacturing

Creep Curve Modelling of Austenitic Stainless steel 316LN

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Physics based creep models that elucidate the creep deformation behaviour with ongoing microstructural evolution, is the need for components life assessment as well as design of novel materials, deployed at high temperature and pressure. In this research work, a creep model also known as hybrid model, since it is combination of physical based model and CDM approach, is employed to predict the creep curves of steel 316LN. The microstructure-based variables act as input to the developed hybrid model. The model provides a provision for the assessment of each microstructural variable in each time steps, as they are the output of the hybrid model. Consequently, the hybrid model produces the output like dislocation density (mobile and forest), dislocation velocity, dislocation mobility, mean free path, internal stress, effective stress and damage parameter evolution. Input parameters that are various dislocation densities and mean free path are obtained from the literature and assimilated in the hybrid model. Predicted creep curves are in good agreement with experimental ones.

Keywords: Creep modelling, Dislocation density, Internal stress, Precipitate, Mobility

Understanding the Effect of Microstructure on Load Reversal and Low Cycle Fatigue Behaviour of Single and Multi-phase Alloys using Crystal Plasticity Finite Element Method

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The microstructural origins on deformation and damage mechanisms in load reversal and low cycle fatigue deformation of various single and multi-phase engineering alloys has been developed using detailed experimental investigations. However, numerical simulations that capture operation of different slip and twin systems as well as accumulation of stresses and strains at the mesoscale that can contribute to initiation of damage is missing in literature. In the present investigation, we attempt to establish the microstructure-load reversal and low cycle fatigue performance paradigm in single phase FCC and two-phase FCC + BCC alloys using synthetic microstructure generation followed with crystal plasticity simulations. For the same, the synthetic microstructures with different morphologies namely; equiaxed, bimodal, elongated, and gradient single and two-phase microstructures were generated using Neper software. Load reversal and cyclic loading experiments were performed using the finite element software package of FEpX and post processing of the simulated tests was performed to obtain mechanical response, evolution of texture as well as distribution of stress and strain at the grain scale. Neper-FEpX has been efficient in replicating experimental results in case of uniaxial tensile deformation due to its provision for including complicated boundary conditions, constitutive laws for plasticity as well as hardening across the length scale and multiple deformation mechanisms. It is also shown to capture the micromechanical response in cyclic loading of single and two-phase materials. Simulation results show that optimum stress and strain partitioning in gradient microstructures provides the best cyclic loading performance highlighting the need to engineer different levels and types of gradients to improve cyclic properties of metallic materials.

Investigating the Influence of Strain Rate on Stress-strain Behaviour for Different Grain Morphologies using Crystal Plasticity-based Finite Element Method

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The mechanical behaviour of any material is significantly affected by its microstructural morphology. Hence, to get the desired material performance, microstructural engineering plays a key role. In this work, various synthetic microstructures having different morphologies were generated by the software package, Neper. The microstructures were then meshed and uniaxially deformed. The deformation was run using a Finite Element Method (FEM) based crystal plasticity simulation in FEpX. In this uniaxial loading, they were tested under different strain rates ranging from 1.25×10^{-4} s^{-1} to 0.1 s^{-1}. The motive was to analyse the stress-strain behaviour and to correlate the outcome with the probable mechanism occurring in the level of slip systems. For single-phase microstructure, copper-based material parameters were used. Again, in the case of dual-phase, iron was incorporated alongside copper. For different morphologies and strain rates, different mechanical behaviours were observed, and the corresponding variations were noted.

Keywords: Deformation, Mechanical behaviour, Crystal Plasticity, CPFEM, Strain rate

Effect of Multiaxial State of Stress on Mechanical Properties of Gr.92 Steel

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The tensile and creep studies have been carried out on smooth and notched (notch acuity ratio: 1-20) specimens of grade-92 steel. Tensile tests were performed at $3x10^{-4}$ s^{-1} and at 300 and 923 K. Presence of notch increased the tensile strengths of the steel as compared to plain specimen for both at 300 and 923 K. Both, yield stress and ultimate tensile strength of the steel increased with increase in notch acuity up to 4. Tensile strengths of the steel are comparable at notch acuity range between 4 to 20. Creep tests on notched specimens were carried out at 923 K at 140 and 150 MPa applied stress. The creep rupture life of notched specimen increased up to a notch acuity of 4 as compared to the plain specimen. The increase in creep rupture life is about ~10 times in the specimen having notch acuity of 1 and 2, whereas creep rupture life increased about ~2 times for the notch specimens having acuity ratio of 4 than the plain specimen. The significant loss of creep rupture life in the notched specimens is observed with further increase in notch acuity beyond 4. The loss of creep rupture life in the notch specimen having acuity above 4 is about ~80% as compared to the plain specimen. Finite element analysis has been carried out to understand the change in mechanical properties with multiaxial state of stress.

Keywords: Notch, Tensile, Creep, Grade-92 steel

A Machine Learning Based Approach for Cold Spray Deposition Microhardness Prediction from Processing Parameters

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Cold spray is a high-speed solid-state deposition technique that allows for fabricating coatings and free standings structures by carefully tuning interdependent processing parameters. In this study, the trained machine learning (ML) algorithms are utilized to predict the microhardness of the cold spray coatings. A set of 100 data points were collected from various different literature which depicted the variation of deposition microhardness in cold spray additive manufacturing (CSAM) with different processing parameters viz, heat capacity ratio of processing gas, Processing gas temperature (^oC), Processing gas pressure (MPa), Standoff distance (mm), Powder material density (g/cm3) and Substrate density (g/cm^3). Six different ML algorithms were used were trained and compared for prediction. The Ada boost algorithm showed the best predictions with R^2 fit of over 0.95 for the testing data and 0.83 for unknown data. High R^2 scores indicated that the ML models were able to predict the deposition micro-hardness based on the given input parameters with reasonable error and accuracy.

Failure Analysis and Life Enhancement of Skirt Lifting Tie Rod which is Failing by Pre-Mature Elongation

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Skirt lifting tie rod is a critical part used for lifting and lowering mechanism of heavy skirt of vessel. These tie rods are under tensile loading condition and share approximately 24 ton loads distributed evenly on four tie rods in each vessel. These tie rods lift and lower the skirt hydraulically at an ambience of elevated temperature of above 750 °C. These four tie rods are failing prematurely due to elongation and leading to safety concern by falling of movable hood. The existing material AISI 431 has average life of 3-4 months as the tie rod thinning and length increases drastically. The microstructure of affected region of tie rod revealed micro voids with grain boundary chromium carbide precipitates which indicated tertiary creep due to microstructural degradation at high temperature exposure over long period. The yield strength and UTS of affected region of tie rod deteriorated due to creep and found to be much lower than unaffected area. The yield strength and UTS deteriorated due to creep and found to be much lower than the designed stress. The material used for this application need to withstand a working stress of 6.3 MPa at a temperature of 750 °C for minimum one year (8760 hours). However, literature suggests that the existing material AISI 431 can withstand a stress which is below 5 MPa as per our necessary requirements; therefore, existing material was suitable for such application. Simulation of super alloy Inconel 617 has been done in Ansys by a coupled static structural and steady state thermal model that shows superior creep properties in such a condition.

Keywords: Creep, Inconel 617, Grain boundary voids

Invention of Superior Colour and Thermal Stable Iron Oxide Pigments

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The iron oxide-based goethite (FeOOH) is proven to be an alternative replacement for carcinogenic chrome based yellow pigments e.g. lead chromate, strontium chromate, and benzidine yellow. Because of its low thermal stability, it tends to lose water of hydration and turns red or brown as temperature ascends beyond 220 ºC. As a result, their use is limited in powder, coil or high-temperature coatings. To circumvent this problem, the industrial grade (IG) goethite pigment has been investigated. In this study, the industrial grade (IG) goethite from a commercial plant has been surface treated with sequestering agents to reinforce its colour and thermal properties. XRD and FTIR results were examined for both bare and surface treated IG goethite to understand the effectiveness of the treatment. The XRD results confirmed that there was no phase conversion of goethite to hematite even at 300 ºC for the treated samples. Whereas, phase conversion and dehydroxylation has started ocurring between 260-300 ºC in the bare goethite samples. Also based on the colour difference (DE) value of 0.74 using a color spectrophotometer, it was observed that colour properties of surface treated IG goethite pigment were retained even after exposing it to 280 ºC. The outcome of the research has been commercially implemented in a commercial manufacturing unit. This implies that surface treated IG goethite pigment can be employed in formulation for high-performance coil, powder and high temperature coatings.

Keywords: industrial grade (IG) goethite, surface treated, Sequestering agents, thermal resistance, XRD, colour difference (DE) value

Microstructural Characterization and Mechanical Behavior of Additively Manufactured Al alloys

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Two additively manufactured alloys of aluminum, the AlSiMg alloy and a new AlMgSc alloy, prepared via the laser powder bed fusion (PBF) technique, were evaluated for its microstructure and mechanical properties. PBF AlSiMg alloy has demonstrated moderate strength (120 MPa) and ductility (10%) at room temperature. The novel Al-Mg-Sc alloy printed by PBF-LB/M is found to possess higher room temperature yield strength (450 MPa). This study examines a detailed characterization of the respective alloys, starting with the powder characterization, density, microstructure and room temperature mechanical properties. Attempts have been made to prepare and evaluate a hybrid AlSiMg-AlMgSc alloy with a view to use the hybrid towards repair and restoration involving complex interfaces via additive manufacturing.

Keywords: Additive Manufacturing, Laser Powder Bed Fusion, AlSiMg, AlMgSc, Hybrid, Microstructure, Mechanical Properties

Study on Energy Density and its Influence on Single Track Inconel 718 Processed through Selective Laser Melting

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Selective Laser Melting (SLM) is a laser powder bed fusion (LPBF) process under additive manufacturing (AM) that uses a laser heat source to melt a metal (alloy) powder bed and build final parts directly. The high solidification rate associated with the process results in a unique microstructure and mechanical properties. Such microstructures are dependent on the process parameters such as laser power, scan speed, hatch spacing and layer thickness, which can be collectively categorised as energy density. The present study aims to look into the effect of energy density and its influence on single track formation and its microstructure. FE based simulation studies were conducted at different energy densities to determine the regions of conduction,

keyhole and transition melting modes by varying the laser power and scan speed. Single-tracks were processed based on the simulation results to confirm the melting modes and also to check for macro and micro segregation of elements such as Nb, Ti and Al along with carbides within the melt pool. It was seen that in the energy density level of 10.5 J/mm^2, higher laser power led to the transition from conduction to keyhole mode. It was observed that the grain size and orientation were highly influenced by both the laser power and energy density. Keyhole mode of melting resulted in long columnar grains with high aspect ratio while low laser power with low energy density resulted in short columnar grains with equiaxed grains near to the melt pool boundary. EDS analysis showed no segregation at all energy density combinations. Microhardness of the single track showed that the hardness variation with respect to laser power for a given energy density was negligible, but energy density had a slight influence with 10.5 J/mm^2 having the highest hardness while 8.5 J/mm^2 had the lowest.

Low-cost Chemiresistive Sensing of Lead by β-cyclodextrin Functionalized rGO Film

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Heavy metals bind with proteins and pose a potential risk to human life when exposed to higher concentrations. Thus, precise and quick detection of heavy metals is essential. Reduced graphene oxide has become a reliable material for heavy metal sensing applications as they possess properties such as large surface area, high electrical conductivity and ability to interact with various chemical species. Here, we report the use of β-cyclodextrin (BCD) functionalized reduced graphene oxide (rGO) as a chemiresistive sensor material for lead (Pb(II)) sensing in the aqueous medium. Functionalization of rGO led to selectivity towards lead detection. A significant change in resistivity was observed within 15 minutes when the BCD functionalized rGO film was exposed to $Pb(NO_3)_2$ solution of various concentrations. A chemiresistive device was fabricated and characterized. The development of cost-effective and selective chemiresistive sensors is expected to provide a facile solution for heavy metal detection for point of use sensing devices.

In-situ Polymer-Derived SiC Reinforced Aluminium Composites

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Aluminium metal matrix composites are being used in a wide range of applications due to their superior combination of properties and cost effectiveness. These have structural and functional applications in many fields such as aerospace, automobiles, electronics, thermal management and sports. The primary challenge faced in the production of aluminium matrix composites is the uniform distribution of particles in the matrix and optimisation of interfacial reaction. In the present work, SiC reinforced aluminium matrix composites are produced by insitu pyrolysis of a polymer precursor (allyl hydrido polycarbosilane). In-situ aluminium matrix composites were fabricated by stir casting route, using aluminium mixed with powdered crosslinked polymer precursor. Pyrolysis of the polymer was achieved in-situ at a melt temperature of 750 °C under an inert atmosphere. Pure aluminium casting was also prepared under similar conditions for comparison with the synthesised composite. Characterization of samples using Raman spectroscopy, X-ray diffraction and optical microscopy confirms presence of reinforced ceramic particles. The results revealed a considerable improvement in the mechanical properties of the aluminium-based composites after the in-situ reinforcement. Ultimate tensile strength (UTS) increased by 77%, hardness by 40% and compressive strength by 44% (strain = 0.2) with reduction in strain at UTS of 9.5% for a ceramic reinforcement of about 4%.

Effect of Surface Roughness on the Friction and Wear Characteristics of A356 Alloy and A356/10%SiC_p Composite Dry Sliding against EN31 Steel in Reciprocating Contacts

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The aim of this work is to determine the effect of counter-plate surface roughness (0.101, 0.145, 0.243 microns) values on wear rate and coefficient of friction of A356 alloy and its composite at room temperature in reciprocating contacts. A356/10%SiC$_p$ composite was prepared by stir casting method with the addition of average particle size of Silicon carbide (SiC) particles as 32 µm uniformly throughout the process. The microstructure and hardness correlation were done using the Optical microscopy and Brinell Hardness machine. Heat-treated pins were used for the reciprocating wear test along with different roughness values of EN31 steel counter-plates (0.101, 0.145, 0.243 µm). Experiments were conducted for a duration of 30 minutes at a constant load of 30 N by varying the sliding speeds (0.2, 0.4, 0.6 m/s). All the tests were conducted at a fixed stroke length of 100 mm. Results showed that the wear rate of the alloy increases with increase in counter-plate roughness at low sliding speeds. Whereas the wear rate of the composite keeps on increasing with increase in counter-plate roughness irrespective of the sliding speed. In the case of alloy, irrespective of sliding speed the COF first increases and then decreases with increase in counter-plate roughness. While in the case of composite, the COF keeps on increasing with increase in roughness at low-speed sliding. During high-speed sliding, filling of the asperity gap of EN31 steel counter surface greatly reduced abrasion between the mating surfaces, this in turn resulted in the reduction of COF and wear rate.

Keywords: Surface roughness, Al-Si alloy, Composite, Reciprocating wear

Characterization of Ti-6Al-4V and IN625 Powders suitable for Additive Manufacturing

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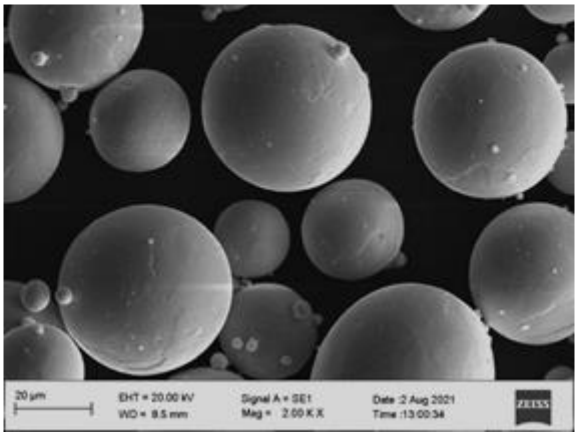
Additive Manufacturing (AM) is enabling unique and better ways to rapidly manufacture intricately designed products for various end-use applications. Powders play a vital role in AM and influence the properties of the final part such as tensile strength, ductility, microstructure, etc. Therefore, a detailed characterization of powders becomes very crucial to assess their suitability for AM by different processes like Powder Bed Fusion (PBF) and Directed Energy Deposition (DED). The present study is aimed to carry out the comparison of four different grades of AM powders produced through Gas atomization and Plasma atomization processes viz. Plasma atomized Ti-64, Gas atomized Ti-64, Gas atomized IN625 coarse (DED) and fine (PBF) powders. The physical, chemical & flow characteristics of powders viz. Flow rate, oxygen content, particle size distribution, apparent density, chemical analysis, internal porosity, satellite content, grain size and morphology were analyzed as per ASTM standards and image analysis. Plasma atomized powders have shown narrow range of particle size distribution compared to gas atomized powders. SEM and optical microscopy analysis revealed less internal porosity and satellite content in plasma

atomized powders. Back scattered electron micrograph and XRD confirmed the presence of α, β phases in Ti-64 powders and SEM analysis has shown presence of Widmanstatten structure in Ti-64 powders, whereas, a dendritic structure in IN625 powders. Chemical analysis has brought out that plasma atomized powders has less oxygen pickup as compared to gas atomized powders. Apparent density tap density as well as hall flowability of plasma atomized powders is better compared to gas atomized. Gas atomized Ti-64 powder was found to be not flowing through standard hall-flowmeter due to irregular surface morphology and van der Waal's attraction forces. IN625 coarse (DED) powders shown very good flowability compared to IN625 fine (PBF) powders fulfilling the flowability criteria of DED 3D printing.



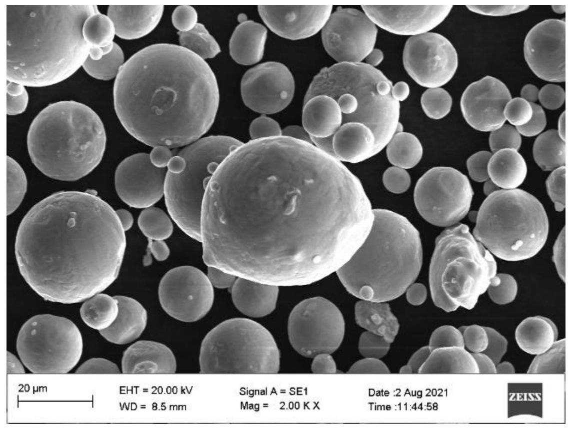


Fig 1a. SEM micrograph of Plasma atomized Ti-64
Fig 1b. SEM Micrograph of Gas atomized Ti-64

Engineering the Coating Texture in Electrodeposited Sn Coatings for Improved Corrosion Resistance

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Sn electrodeposits are widely used in electronic industry as interconnects [1]. Whiskering, corrosion, and thermomechanical stress often lead to failure of the interconnect, and thus, various methods are routinely explored and adopted to improve the mechanical and electrochemical stability of Sn electrodeposits essentially by modifying their morphology and microstructure. In this work, Sn electrodeposition was performed over polished mild steel substrates at four different bath temperatures: 24 ˚C, 47 ˚C, 70 ˚C, and 80 ˚C. The Sn coatings were subjected to corrosion analysis using the potentiodynamic polarization measurements, and the corrosion resistance data

was correlated with the electron backscattered diffraction (EBSD) results. It was observed that the Sn coating fabricated at 70 ˚C exhibited the highest corrosion resistance while the corrosion resistance of Sn coating fabricated at 80 ˚C was the least. EBSD analysis revealed that the 70 ˚C coating exhibited a low surface energy '(001)-(100)' texture [2-3]. While the 24 ˚C and 47 ˚C coating exhibited high surface energy 'near-(110)' texture. Additionally, increasing the electrodeposition temperature increased the average grain size of the coatings. Five-parameter grain boundary plane distribution analysis along the 62.8˚/ [100] misorientation angle-axis pair showed high intensity at (031) pole for Sn coatings prepared at 47 ˚C, 70 ˚C, and 80 ˚C, indicating a high population of Σ33a (031) [013−]031013- twin boundary, which is a low energy boundary in β-Sn structure. The high corrosion resistance of the Sn coating deposited at 70 ˚C can be attributed to the following factors: (i) crystallographic texture along low energy (001) and (100) orientations, (ii) high fraction of low angle grain boundaries(LAGBs), and (iii) high fraction of Σ33a twins. A low fraction of Σ33a twin boundaries coupled with near-(110) orientation texture exposed towards corrosive medium led to the low corrosion resistance of the Sn coating deposited at 80 ˚C.

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On the Differences in the Shear Band Characteristics between a Binary Pd-Si Metallic Glass and Nanoglass

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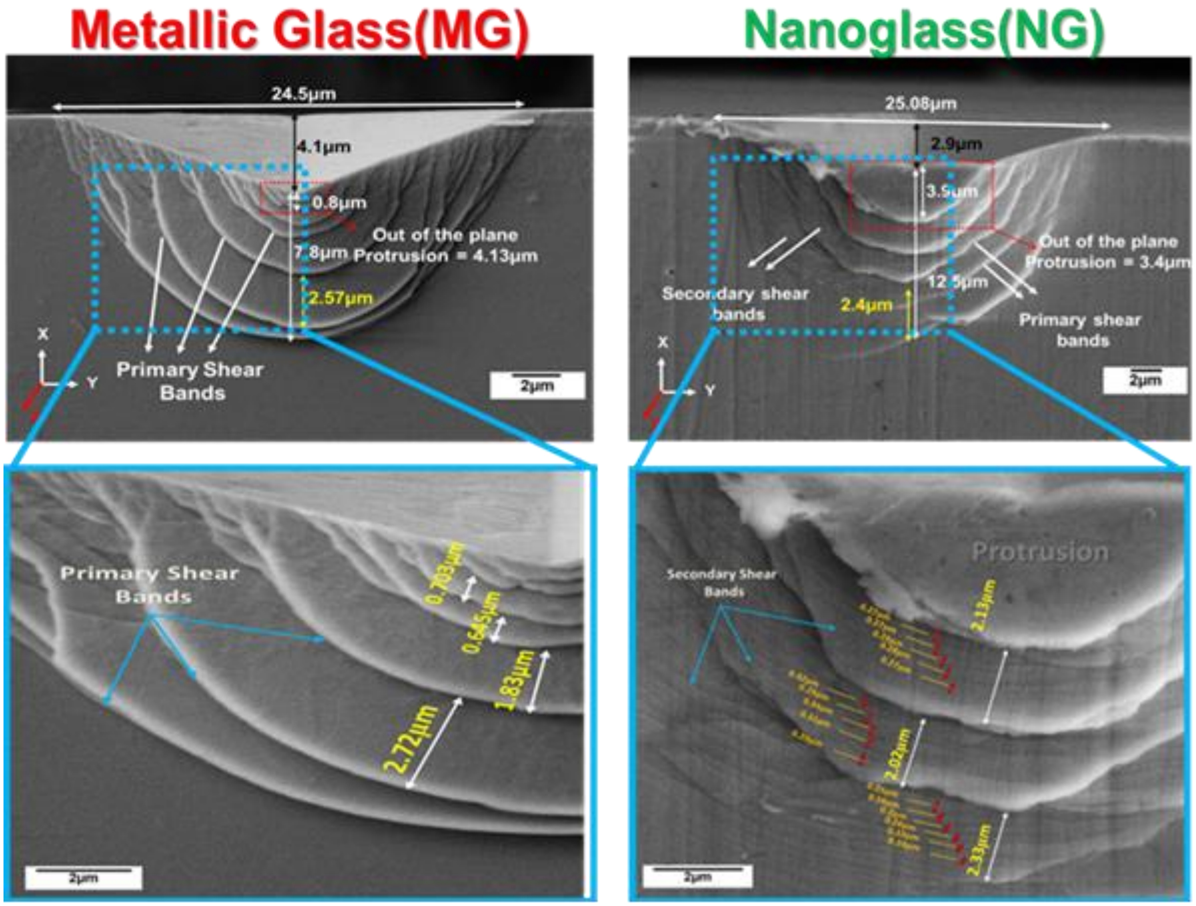
Shear band morphology of a binary $Pd_{80}Si_{20}$ nanoglass (NG) and metallic glass (MG) was investigated using bonded interface indentation technique. The results clearly indicate that the plastic strain in the subsurface deformation zone in NG is accommodated by very fine secondary shear bands in addition to a fewer primary shear bands while in MG it is mainly by primary shear bands. Furthermore, at any given indentation load, the size of the normalized subsurface deformation zone, χ, is found to be higher for NG compared to MG suggesting that the deformation of $Pd_{80}Si_{20}$ NG is more pressure sensitive and softer than MG. These differences in deformation

characteristics between the NG and MG closely related to the intrinsic differences in the glass structure.



Failure Investigation and Life Enhancement of Bent Pipe used in Wire Rod Mill

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Bent pipe is a thick-walled hollow pipe located in between the pinch roll and laying head of the wire rod processing line, which guides wire rod feeds from mill to the laying head. The pipe is not straight, and the bending of the pipe is designed in such a manner so that it can accommodate the level difference in between the pinch roll the laying head in the WRM of ISP.

The bent pipe is liable to absorb high degree of mechanical shock as well as thermal fatigue due to high temperature processing of wire rods. Thus, significant abrasive wear of bent pipe takes place during operation and.as a result it fails almost regularly after around 1200T of rolling. This kind of failure of bent pipe is predominant in lower section plain wire rods which are rolled at relatively higher speed. To avoid the recurring event of cobble, bent pipe is changed almost every day, resulting into high consumption of bent pipe.

The failure of bent pipe was investigated by metallurgical investigation. The material of the bent pipe was heat treated in laboratory. All metallurgical parameters of the bent pipe were analysed after heat treatment. The most suitable heat treatment parameters were finalized for bent pipe. Trial with modified heat-treated bent pipe was performed at WRM, ISP. Life of bent pipe was improved by 155.50% over the existing pipe.

The Effect of Duty Cycle and Subsequent Annealing Process on Grain Growth during Pulse Reverse Electrodeposition in the Copper Foil

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The effect of duty cycle on the evolution of microstructure and texture were characterized before and after contact-free annealing. Copper foils were deposited on a stainless-steel substrate using a pulsed reverse electrodeposition technique in a medium of copper sulphate bath. With increasing duty cycles from 60 to 90 %, while the average grain size decreases from 8.5 ± 6 µm to 4 ± 2.7 µm, the fraction of twin boundaries increases continuously in the as-deposited conditions. Interestingly, after high-temperature (at 1050 °C) annealing for a long duration (for 6 hours), the formation of {100} fiber is heavily suppressed, while a significant fraction of interconnected twinned regions is visible in all Cu foils. Twin related domains (TRD) are clusters of many grains that are connected by twin boundaries and are generally non-breakable. The average size of the TRDs, after contact-free annealing, was observed to be 128, 119, and 115 µm for 70, 80, and 90% duty cycles, respectively. These results show that it is possible to suppress the evolution of {100} fiber and maintain a high fraction (>60 %) of twin boundaries in annealed Cu foils.

Heat Transfer and Material Flow Modelling for Multilayer Deposition in Laser-assisted Directed Energy Deposition AM Process

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Additive Manufacturing (AM) of three-dimensional object possess repeated heating and cooling cycle. Therefore, the temperature distribution around the deposited structure affects the defects, microstructure, and properties of the final specimen. For the same reason, the process parameters need to control by hit and trial take effort. The process parameters control in the additive manufacturing process is time-consuming and wastage of resources. Therefore, the heat transfer and material flow numerical model are developed to compute the temperature field for the multilayer deposition. The numerical model solves various physical phenomena such as heat transfer due to conduction and convection, Marangoni effect, re-melting, and solid to liquid phase change. The model computes the thermal cycle, fusion zone shape and size, velocity field, and solidification parameters.

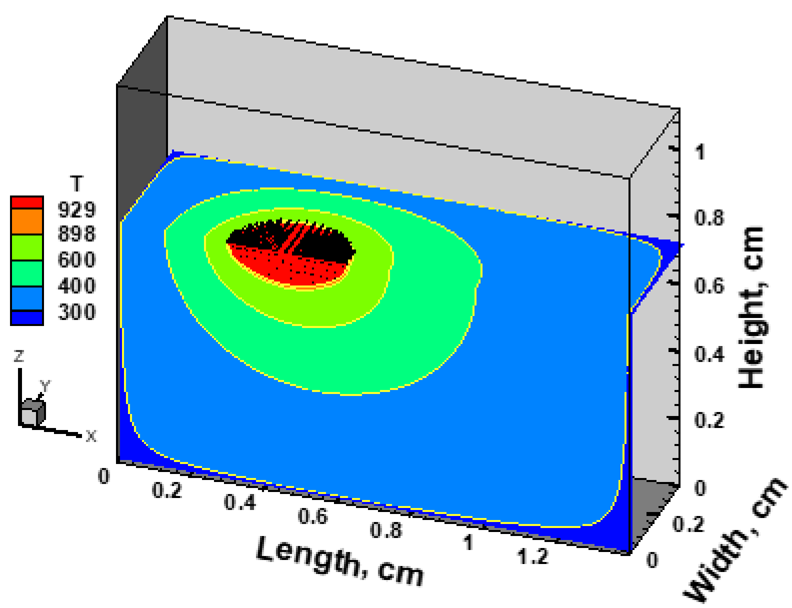

Figure: Temperature distribution for multilayer deposition in the laser-assisted directed energy deposition process

Mechanical and Corrosion Behavior of Friction Stir Processed Aluminum Matrix Surface Composites

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Aluminum alloys find application in aerospace, automobile and structural sectors. However, these alloys are susceptible to corrosion attack in chloride environments. Introducing a second species on the surface by surface composite fabrication can be a way to increase the corrosion resistance of the aluminum alloys. Here we present corrosion studies on aluminum matrix surface composites fabricated using friction stir processing. The reinforcement of Mo particles is considered with varying percentage and distribution in the surface composite. The particle content and distribution are analyzed using SEM-EDS and Optical image analysis. Based on the potentiodynamic polarization analysis, the surface composites exhibit improved corrosion resistance with higher corrosion potential and lower corrosion rate. Increase in corrosion resistance is observed for higher Mo content with homogenous distribution. While the base alloy exhibit mixed corrosion behavior, the surface composites show charge-transfer controlled corrosion behavior in the Electrochemical Impedance Spectroscopy. Reduced pitting in the Mo rich areas is confirmed by microscopic analysis of the corroded material.

Design of Additive Manufactured High Strength Steel: CALPHAD based ICME Approach

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The materials by design approach open a platform to develop new materials computationally. This approach is cost-effective and time-efficient and does not depend on the traditional discovery approach which is based on rigorous experiments. In the present study, CALPHAD-based integrated computational materials engineering (ICME) methods were implemented to optimize the composition of high-strength steel. HSLA-100 was considered as reference material for the

optimization. The system design chart of process-structure-property-performance for high-strength steel was designed. To achieve the target performance and desired properties, microstructure and process parameters were designed. The driving force of phases and precipitates were calculated using Thermo-Calc software. Phase fraction and step calculation were performed using Thermo-Calc. Additional bainite starts temperature, martensite start temperature, and printability models were incorporated into TC API using C programming to optimize the prototypes composition.

Serrated Plastic Deformation and Multi-necking Behaviour of 16Cr-6Ni Austenitic-Martensitic Stainless Steel at 20 K

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16Cr-6Ni (ICSS-0716-301) austenitic-martensitic transition class stainless steel is widely used as a structural material in cryogenic engineering because of its outstanding mechanical behaviour especially at low temperatures. Tensile experiments have been conducted on 16Cr-6Ni alloy at 20 K to obtain mechanical properties. This alloy steel exhibits serrated plastic deformation, a series of sudden load drops accompanied by a well-audible click, starts from the initial stage of plastic deformation and occurred repeatedly until fracture at 20 K. Multi-Necking also detected on the tested specimens. Cryogenic temperature is the important drive to the occurrence of this phenomenon. The most probable mechanism is that of adiabatic deformation: local heating of the sample which is permitted by low heat capacities and thermal conductivities of metals at low temperature range. Scanning electron microscopy (SEM) and Optical microscopy (OM) results are presented to discuss the possible reason of multi-necking. In additional, an optical method is used to gauge the geometry of multi-necking specimens.

Keywords: Serration, multi-necking, 16Cr-6Ni alloy, Tensile test at 20K

Data-driven Approach to design of Multicomponent Metallic Glasses

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Despite several parameters and criteria proposed by exhaustive studies to develop a robust alloy design strategy, accurate predictions of glass formation in multicomponent systems remain an open subject and a challenge. The atomic topology, which is critical in stabilizing short-range atomic clusters, is central to the design of Multicomponent Metallic Glasses (MMGs). The current study demonstrates that incorporating the Mendeleev Number (MN), an elemental property parameter, into the definition of topological parameters can be used as a valuable tool to predict MMG alloy systems more accurately. The incorporation of MN into the design strategy emphasizes the importance of electronic interactions between atoms and bond orbitals in the amorphous phase formation in multicomponent alloy systems. This understanding of atomic topology, together with other key physical, thermodynamical, and kinetic features, was used to develop a near-foolproof design strategy for multicomponent metallic glasses (MMGs) prediction using machine learning (ML). Feature engineering was used to optimize the descriptor space, and various ML algorithms were used to classify the amorphous multicomponent alloys over crystalline counterparts. Based on various evaluation metrics, the Support Vector Machine (SVM) algorithm emerged as the best classifier, with a testing set accuracy of 92.7 %. The modelling results also show that formation thermodynamics, atomic size difference, and synthesis kinetics play important roles in the amorphous phase formation in multicomponent alloys. Several novel high entropy alloys (HEAs) were synthesized into ribbons *via* melt spinning and characterized based on the ML model's predictions to validate its outcomes. The developed SVM model can predict likely MMG compositions without any prior experimentation, guiding the development of MMGs in an unconstrained manner.

Estimation of Intrinsic and Tracer Diffusion Coefficients from Multicomponent Diffusion Profiles

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Multicomponent diffusion analysis in inhomogeneous materials had been a lingering issue in the field of material science until recently. Unpredictable diffusion paths cannot be intersected in multicomponent space for the estimation of interdiffusion coefficients at the composition of intersection. The recently developed pseudo-binary (PB) and pseudo-ternary (PT) diffusion couple techniques established in our group enabled the calculation of interdiffusion coefficients by restricting the diffusion paths following certain conditions. One may also follow the body-diagonal (BD) method proposed by Morral for estimation of these diffusion coefficients when diffusion paths pass closely instead of intersecting. However, estimation of intrinsic coefficients necessary for understanding diffusional interactions between components still remained a challenge in multicomponent systems, which are also important for microstructural simulations.

Here, we have proposed an augmented Darken-Manning approach for the estimation of main intrinsic and tracer coefficients at the Kirkendall marker plane of a PB diffusion couple [1, 2]. An augmented Kirkaldy-Lane method for estimation of tracer, main and cross intrinsic diffusion coefficients following the PT and BD diffusion couples is also established. Further, this is extended for the estimation of these parameters at the cross of different types of diffusion paths. These are demonstrated at the equiatomic composition of NiCoFeCr for the sake of comparison with the tracer diffusion coefficients measured by the radiotracer methods to find an excellent match. This method can be now extended to Al, Ga, Si containing systems in which radiotracer method cannot be used because of unavailability of suitable radioisotopes.

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Gram-scale Solvent Free Synthesis of High Quality, Defect free Single-layer Graphene with Low Percentage of bi/tri-layer

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Graphene, a single atomic layer 2D carbon crystal exhibits remarkably high carrier mobility (2×106 cm^2 V^{-1} s^{-1}), electrical conductivity (2×10^3 S m−1), thermal conductivity (5×10^3 W m^{-1}

K^{-1}), mechanical strength (1 TPa), specific surface area (2.6 x 10^3 m^2g^{-1}) and excellent environmental compatibility. However, obtaining single layer graphene (SLG) is very challenging and most of the commercially viable protocols synthesize multi-layer graphene (MLG) instead of SLG. As commercial application of graphene keeps growing, it is essential to mass produce high quality graphene sheets. New findings face formidable challenges in marketplace due to lack of proficient protocol to produce graphene in commercial scale while maintaining its quality. Here, we present a clear technique for the ultra-fast exfoliation of graphite into high quality, defect-free graphene in gram-scale without the use of any intercalants, chemicals or solvent. We report that graphite can be exfoliated using plasma spray technique with high single-layer selectivity (~85%) at a very high production rate (48 g/hr). This is possible because of the inherent characteristics of the protocol which provides sudden thermal shock followed by two-stage shear. The exfoliated graphene shows almost no basal defect (I_d/I_g: 0), possess high quality (C/O ratio: 21.2, sp^2 %: ~95%); an indication of negligible structural deterioration. The results were highly reproducible indicating the adeptness of the protocol. Several proofs of concept confirmed that our plasma spray exfoliated graphene can be commercially exploited in applications such as mechanical reinforcements, frictionless, transparent conductive coatings and energy storage devices.

Investigating Microstructural and Microchemical Effect of Ageing on Cu-rich Phase of Super 304H SS Exposed to Chloride Environment

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SS 304H Cu (18Cr-9Ni-3Cu-Nb-N) is chosen as a candidate material for superheater and reheater tubing of advanced ultra-supercritical (AUSC) boiler applications for achieving higher thermodynamic efficiency by operating at temperatures and pressures of 710/720 °C respectively which are significantly higher than sub-critical (conventional) and supercritical power plants. In the present study, efforts have been made to assess pitting corrosion behavior of SS 304HCu prior and after aging for 20000 h, 10000 h and 5000 h at 973 K to simulate the operating condition of about 2 years and 1 year respectively. However, prolonged exposure of these alloys to high temperatures during service could lead to Cu precipitation, whose role on corrosion properties needs an investigation. Critical pitting potential (Epp) decreased with ageing. The parameters indicating passive film stability measured by EIS revealed faster passive film dissolution as indicated by low polarization resistance, in aged condition. The EIS results correlated well with the variation in the respective Epp obtained from the potentiodynamic polarization

diagrams. Microstructure and morphological variations in thermally aged specimens were used to explain the above variation in the corrosion properties.

On High Temperature Wear Behavior of a α+β-titanium Alloy

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High temperature wear behavior of an aerospace grade α+β-titanium alloy was investigated under dry sliding conditions at 25 °C and 400 °C. Various parameters such as load, sliding distance and temperature were considered to determine the wear rate. The alloy shows excellent wear resistance at 25 °C when compared with 400 °C. Post wear analysis indicated that the delamination of oxide layer from the specimen surface attributed to the poor wear resistance of these Ti alloys at 400 °C. Presence of titanium dioxide (TiO_2) particles on the worn surface as well as in wear debris from SEM-EDS analysis shows the delamination of oxide layer due to lower shear strength which resulted in the loss of material.

Influence of Local Microstructure on the Dislocation Transference and Micro-mechanical Response in Metastable FCC Alloy

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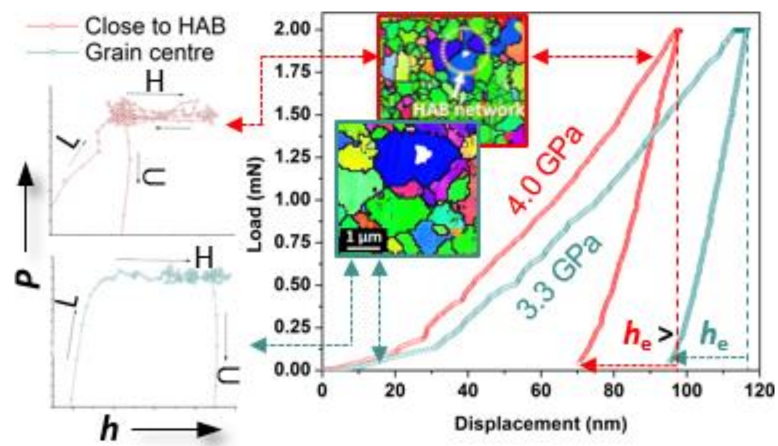
This work underscores the effect of local microstructural configuration on the dislocation movement and micro-mechanical behaviour in fine/ultra-fine-grained (< 2 μm), cold-rolled and annealed 301L austenitic stainless steel by site-specific nanoindentation experiments. Indentation loading, holding, and unloading behaviour have been studied separately for five different microstructural categories. Hardness and modulus vary proportionally from one indentation to another. It has been observed that a large density of high-angle boundaries most competently

restricts the dislocation motion (strain hardening) resulting in high hardness. However, the back stress generated by the dislocation pile-up aids recovery during holding/unloading. Contrarily, the coarse grain reveals lower hardness attributed to easy dislocation transmission and a lesser elastic recovery during holding/unloading owing to an insufficient back stress in the absence of a favourable dislocation pile-up. The observation is against the general expectation considering the grain size dependence of the formation of pileups in ductile materials subjected to large-scale deformation. Interestingly, low-angle boundaries interact more with the dislocations and form such a defect structure that the strain locally reaches the critical value for the formation of deformation-induced martensite following Kurdjumov-Sachs orientation relationship with the parent austenite.



High Temperature Cyclic Corrosion of Inconel 738 Superalloy at 700 ^{0}C by Coating the Material with Different Chemical Compositions of NaCl, Na_2SO_4, V_2O_5 in Air

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In present study high temperature cyclic Corrosion behaviour of Inconel 738 superalloy was studied. The cyclic Corrosion test was carried out at 700^{0}C for 10 cycles. Each sample was coated with 10 different combination of chemical composition of NaCl, Na_2SO_4, V_2O_5. After coating, each sample was placed in the furnace. The cycle was consisting of 1 hr of heat treatment at 700 ^{0}C in muffle furnace. Then the samples were removed from the furnace and allowed to cool in the air environment. The weight gain after every cycle was measured and used to determine the

kinetics of oxidation. The rate constant (parabolic rate constant, k_P) was determined from the weight gain data. SEM and X-Ray Diffraction (XRD) was used to analyse the corroded sample. The graph of weight gain/Area Vs no of cycles was plotted. The parabolic rate constant, k_P was higher near to 9×10^{-7} for equal composition of Na_2SO_4 and V_2O_5 in the ratio 1:1 while it was lower for coating of NaCl, Na_2SO_4 and V_2O_5 combined in the ratio 1:1:1.

Influence of Direct Ageing on Microstructure, Mechanical Properties and Pitting Corrosion Behavior of AA2219-T87 Al-alloy Gas Tungsten Arc, Electron Beam and Friction Stir Welds

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Construction of cryogenic fuel tanks is made possible by using AA2219-T87 as the primary material. Despite the fact that base metal has good corrosion resistance and mechanical characteristics, welded joints have poor mechanical properties and corrosion resistance. In light of the aforementioned issue, the current work seeks to improve the better combination of mechanical properties and corrosion resistance of welds through direct ageing. It is accomplished by the investigation of microstructural changes that occur during welding process and post-weld heat treatment processes, as well as their effect on the mechanical characteristics and pitting corrosion behaviour of the AA2219-T87 alloy. In this investigation, gas tungsten arc welding, electron beam welding, and friction stir welding processes were used. PWHT (post weld heat treatment) was performed on all welds using the direct ageing technique. Optical Microscopy was used to investigate the microstructural changes that occurred in distinct zones of welds. Potentiodynamic polarisation testing was used to investigate the pitting corrosion behaviour of base metal, welds and PWHT welds. The mechanical properties were assessed by measuring hardness and tensile tests. The study established that the mechanical properties and corrosion resistance of welds are greatly influenced by the microstructural changes that occur during the welding process. It was found that the mechanical properties of friction stir welds are superior to those of GTA and EB welds in as-welded condition. The pitting potential gradient across the various zones formed during welding was found to be significantly less for friction stir welds of AA2219-T87 alloy than that for GTAW and EBW welds. Friction stir welds retained better mechanical properties when compared to GTA and EB welds, even after being subjected to post-weld heat treatment. Overall, direct ageing treatment of AA2219-T87 welds resulted in considerable improvement in both mechanical properties and corrosion resistance.

Keywords: AA2219-T87, GTAW, EBW, FSW, Post Weld Heat Treatment and Pitting Corrosion

Creep Damage Model and its Applicability to Long-term Life Prediction of 9% Cr Steels

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9% Cr steels are an important structural material for high temperature steam generator applications in power plants. One of the life-limiting criteria for structural material is the accumulation of creep deformation and damage. In general, creep strength of 9% Cr steels exhibited a breakdown in the long-term due to their microstructural instability. Coarsening of $M_{23}C_6$ precipitates, depletion of solute element from the matrix, precipitation of Z-phase by the conversion of MX phase and subgrain coarsening caused the instability. It becomes necessary to establish a reliable long-term life prediction methodology for the steel based on the evolution of microstructural variables. Therefore, in this analysis, at a first instance, a microstructure-based Dyson-McLean model has been examined to describe the creep behaviour of P9 and Grade 91 steels at 873 K. Since the existing model do not consider the influence of individual precipitates, a modification has been made to account for the effects of coarsening of $M_{23}C_6$ precipitates and conversion of useful MX precipitates on the creep rate of steels. The developed model predicted the experimental creep data appropriately. Using the optimised constants, the influence of individual microstructural variables on creep rate has been established. The rupture strength of Grade 91 steel at 10^5 h at 873 K has been predicted with and without MX number density change using a modified approach. At 70 MPa, damages caused by coarsening of $M_{23}C_6$ and conversion of MX into Z-phase play a major role in decreasing the creep strength of Grade 91 steel. With decreasing number density of MX precipitates, a continual drop in rupture life of the steel has been noticed. The simulated the creep behaviour of P9 and Grade 91 steel at very low stress levels is used to find the rupture strength of steels at 10^6 h at 873 K.

Simulation Methodology for Evaluating the Role of Surface Roughness on the High Cycle Fatigue Life of Additively Manufactured IN718

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Surface features (both external and internal) play an important role in determining the long-term stability in any additively manufactured, near net shape component. Accessibility to measure surface roughness in part locations (after net shape manufacturing) is practically not feasible. Yet, it is imperative to assess the roughness and its implication on the component performance under fatigue loading. The internal structures such as conformal cooling holes that cannot be exposed to surface finishing processes may limit the fatigue behavior of the additively manufactured (AM) parts. This study comprises a simulation framework based on experimental measurements of roughness, and uses a numerical model using Abaqus based on inputs on roughness created using Matlab. FE-SAFE is then utilized to simulate the monotonic and axial cyclic properties as a function of surface roughness. The role of surface roughness on the fatigue life of powder bed fusion (PBF-IN718) is computed using a √area model. S-N curves were generated and validated using the literature. Differentiation between surface roughness and surface defects / features were attempted via this model. This framework is expected to serve to effectively predict the fatigue life of additively manufactured parts.

Effect of Printing Parameters on the Microstructure and Corrosion Behaviour of Selective Laser Melted Inconel 718

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Nickel super alloys such as Inconel 718 is used in the liquid rocket engines due to their excellent mechanical, corrosion resistance and oxidation resistance properties at high temperatures. Additive Manufacturing (AM) has emerged as a very promising technique to produce complex and near net shaped products for the aerospace industry. However, the effect of microstructural defects, anisotropy on the corrosion behaviour of Inconel 718 has not been studied in detail.
In the present investigation, the effect of printing parameters such as laser power and scanning speed on the microstructure and corrosion behaviour of additive manufactured Inconel 718 is investigated. Selective laser melting of the Inconel 718 powders were carried out by varying laser power and scan speed by keeping other parameters such as hatch distance (110 µm) and layer thickness (40 µm) constant. The laser power and scan speed were varied in the range of 200-350 W and 860-1060 mm/s respectively. The samples were heat treated as per AMS 5664 standard. The effect of the printing parameters on the microstructure, type and distribution of phases and defects were studied using optical microscopy, scanning electron microscopy and X ray diffraction. Potentiodynamic polarisation and electrochemical impedance spectroscopy studies were carried out in 3.5 wt. % NaCl to evaluate the corrosion resistance. Corrosion morphology was further analysed using scanning electron microscope.

Repetitive Failure of Shaft & Bearing in Coke Plant: Mechanical Fault

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The wheel bearing and shaft of the Stamping Charging and Pushing machine (SCP) in the coke plant of an integrated steel plant was failing repeatedly. The function of the SCP is to stamp coking coal into a cake before charging into the coke oven and to push out the coke post completion of the coking process. The shaft failed in the fatigue mode and its bearing rollers were found to have spalled with beach marks. One side of the raceway was found to have abraded more than the other side which indicated axial shifting of the bearing and significant misalignment of the shaft. The shaft was made of 42CrMo4 and no metallurgical defect was found. Surface cracks were observed in the unetched microstructure of the bearing, confirming “Rolling Contact Fatigue”. No metallurgical deviation was found in the bearing material. Bearing fatigue life (L10) life was calculated considering no axial load on the bearing and considering an axial load. The calculated fatigue life came out to be 8 years and 5 years respectively. The analysis concluded that shaft failed in bending fatigue caused by improper alignment of the bearing housing and wheel, leading to an increase in the axial load of the shaft and an increase in the bearing clearance; both causing further deterioration of the bearing. The failure of the bearing caused subsequent damage to the shaft and the shaft failed in early fatigue mode. To prevent early and repetitive failure of this kind, regular inspection of the alignment and the bearing clearance has been recommended along with ferro-graphic analysis of the bearing grease on a quarterly basis.

Keywords: Fatigue, Bearing, Misalignment, L10 life

Weld Metal Composition of Austenitic Stainless Steel and Duplex Stainless Steels with and without Nitrogen in the Shielding Gas Mixture

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The austenitic and duplex stainless steels have been used widely for anti-corrosion applications. They have good weldability, formabilty, resistance to atmospheric corrosion and do not react easily to the chemicals and food items. Austenitic and duplex stainless steels are generally welded Gas Tungsten Arc Welding (GTAW) process with pure argon gas for shielding. The solidified weld metal contains some amount of ferrite to reduce the hot cracking. Nitrogen being austenite stabilizer, efforts are being made to use it along with argon as mixture so as to reduce the cost of alloying with other austenite stabilizers. In this work, it was decided to estimate the effect of nitrogen in the shielding gas mixture with argon on the microstructure, ferrite number and mechanical properties such as all weld tensile strength and impact energy. Two austenitic stainless steel and two duplex stainless-steel filler wires were used to fill the cavity that has been buttered with same wire on mild steel plates using GTAW process. Buttering and welding conditions were same including the shielding gas mixture. In the welds made with austenitic stainless-steel wires, the shielding gas containing 1% nitrogen-argon showed marked increase in nitrogen content and reduced ferrite number, indicating significant austenite stabilization. The welds made with duplex stainless steels wire showed slight reduction in nitrogen content compared to the filler wire indicating loss of nitrogen during welding; which may be due to electrochemical reaction during the metal droplet transfer from tip of electrode to the weld metal.

Keywords: GTAW, Austenitic SS, Duplex SS, Shielding Gas, Ferrite Number, Stabilizers

Correlation Between Bending and Uniaxial Creep in Additively Manufactured AlSi10Mg Alloy

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Creep behavior of Additively manufactured AlSi10Mg alloy (via the laser powder bed fusion technique) was evaluated at 250 °C, using meso scale testing via "bending", to map the creep response over a range of stresses. Comparisons were made with uniaxial creep (tensile and compressive), in the stress relieved (300 °C, 2h) samples, after a detailed microstructural analysis. Digital image correlation (DIC) is utilized in this study to extract stress and strain profiles. The major advantage of DIC in bending creep is that it enables a high throughput testing as compared to the conventional uniaxial creep tests on multiple specimens. Multiple creep curves can be extracted from a single small-scale specimen tested in bending creep. The differences in build orientation (along and transverse to the build direction) on the creep properties has been evaluated. A detailed microstructural analysis is conducted to understand the observed creep mechanism in this complex additively manufactured Al alloy.

Keywords: Additive manufacturing, Powder Bed Fusion, Creep, Bending Creep, AlSi10Mg

Synchrotron X-ray diffraction studies on neutron irradiated Austenitic stainless steels

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Austenitic stainless steel grades 316 M, 304 L(N) and 316 L(N) are the materials of choice for permanent structures of fast reactors that are subjected to lifetime dose of less than 5 dpa, as opposed to life-limiting dose levels of 60-80 dpa for core structural materials. Mechanical

properties such as tensile strength, ductility and impact toughness of these structural alloys show irradiation hardening, and loss of ductility saturating around and slightly over 5 dpa. Disk specimen of these alloys, neutron irradiated to low dpa levels are being investigated for microstructural effects of low-dose irradiation through electron microscopy and X-ray diffraction with a view to link strength and ductility evolution of the material to defects nature and density. In this regard, synchrotron-based X-ray diffraction experiments are particularly suitable, yielding "bulk" distribution and density of defects, though line profile analysis demands judicious application of techniques to avoid artifacts. X-ray diffraction profiles for the neutron irradiated specimen and corresponding reference specimen were recorded using synchrotron X-ray source, utilizing photon beam of energy ~14.968 keV (wavelength ~0.82833 Å) with beam size of 0.5 mm x 0.5 mm at angle dispersive x-ray diffraction beamline BL-12 of Indus-2 at RRCAT, Indore. Peak broadening, asymmetry and shift in the peak positions as a function of diffraction vector have been systematically quantified over a range of neutron dose levels. In this paper, these results are presented and correlated to the evolution of defects as a function of irradiation dose. Features of the line profiles corresponding to defects specific to radiation damage in face centered cubic alloys such as loops and planar faults will be discussed.

Sol-Gel Synthesis and Characterisation of Crystalline ZrO_2 powders

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A sol-gel synthesis of ZrO_2 powders is carried out by using starting precursor solution i.e. zirconium isopropoxide etc. The effects of some critical process parameters (calcination temperature, aging temperature, nature and concentration of acidic or basic conditions, and H_2O/precursor molar ratio) on the sol-gel synthesis of ZrO_2 powders are studied. The morphology, particle size and distribution, phase evaluation, and chemical analysis of the calcined ZrO_2 powders are investigated by SEM, XRD and EDX respectively. As result, XRD analysis indicates crystalline nature of ZrO_2 powders and all the peaks are belonged to ZrO_2 particles and also confirmed by EDX analysis. SEM analysis indicates the uniformly distributed spherical morphology of ZrO_2 powders. Finally, it can conclude that ZrO_2 powders could be successfully synthesized from the stoichiometry of starting precursor solutions.

Grain Size and Grain Boundary Misorientation Distribution Effects on Thermal Stability of Nanocrystalline Materials

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The effect of the grain size and grain boundary (GB) misorientation distribution on the thermal stability of nanocrystalline materials is described here. The GB misorientation distributions of two synthetic nanostructures, one bearing random texture and other with {111} <110> texture was evaluated. This was converted into equivalent GB energy distributions and basis this, the solute content necessary for reducing the net GB energy of the system was determined. It was observed that the nanostructure with random texture needed a higher amount of solute for reducing its net GB energy. Since GB energy is a measure of thermal stability these calculations highlighted the role of crystallographic texture and misorientation distribution on thermal stability. The effect of grain size distribution was also checked in a similar way as the distribution determines the volume fraction of grain boundaries present in the nanostructure and consequently influences the total grain boundary energy contribution to the nanostructure.

Characterisation of Dissimilar Friction Welds between Titanium and SS 304 l without Interlayer

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Dissimilar joints between titanium (and its alloys) and stainless steel are used in strategic sectors for various critical applications. Challenges associated with titanium and stainless steels welding are their large difference in physical properties like melting point, density and thermal conductivity. These characteristic of the above alloys makes conventional fusion welding difficult. Solid state welding especially Friction Welding (FW) will be one of the candidate processes. Conventionally, FW is performed with an insert of non-ferrous material to prevent the molten SS and titanium from mixing to reduce the formation of intermetallic compounds.

In this work, direct friction welding of titanium to SS 304 L is attempted and welding parameters were optimized on 12 mm dia. coupons. The FW joint resulted in a stronger weld due to lower intermetallics formation at joint interface. The FW joints were characterized through optical microscopy, microhardness, SEM and EDS.

This paper brings out the details of experimentation and optimisation of direct friction joining parameters on the dissimilar material Titanium and SS and evaluation of joint quality through mechanical property evaluation and metallographic analysis. From the study, it has been established that

- FW joints produce joints having parent metal strength (SS 304 L) with sufficient ductility.
- A typical DRX area having very fine equiaxed grains due to severe plastic deformation at high temperature during welding.
- SEM and EDAX analysis confirm presence of secondary phases in the intermix zone near the joint interface.
- No significant difference in microhardness is observed. This infers no significant embrittlement in joint interface of Titanium & Stainless Steel.
- Maximum ultimate tensile strength value of 543 MPa is obtained, which is close to the UTS value of SS 304 L (586 MPa). This shows weld has good joint strength, also the selected welding parameters are considered to be optimum.

Interdiffusion in beta Phase Field of Ternary (Ni, Ru) Al System

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Bond coat plays an important role in multilayer thermal barrier coatings (TBC). These are commonly made of B2 (Ni, Pt) Al, but the presence of Pt makes the bond coats very costly. In order to reduce the overall cost of TBC, Pt can be replaced by Ru. For the development of the Ru based bond coats, knowledge of interdiffusion behaviour of (Ni, Ru) Al is essential. In the present work, interdiffusion behaviour in single B2 phase of Ni-Al-Ru system was studied at 1100 ℃ using the diffusion couple technique. Experimental concentration profiles were obtained using Electron probe micro analyser, which were further fitted by utilising the MultiDiflux software. In this talk, interdiffusion behaviour in terms of the concentration gradients, interdiffusion fluxes and interdiffusion coefficients will be presented.

Corrosion Behaviour of Friction Stir Welded Aa6082 With Aa7075 Similar & Dissimilar Joint

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Corrosion behavior of friction stir welded AA6082 & AA7075 materials joint of similar and dissimilar aluminum alloy was investigated by immersion tests in sodium chloride and nitric acid solution. The optimum parameters are feed rate 80 mm/min, tool rotation speed 900 rpm, tilt angle 2^o. Similar and dissimilar joint of 100 x 100 x 6 mm^3 plate were welded with conical tapered tool pin profile. The tensile strength, microstructure and micro hardness of welded joint were investigated. Corrosion studies includes immersion test by weight loss method and electrochemical method. It was showed that the AA6082-7075 joint has good corrosion resistant in NaCl solution.

Deformation Study of beta Titanium Alloy based on Microstructure and Texture

Unissa Nichul, Vijay Hiwarkar

The room temperature deformation of beta titanium alloy (Ti3Al8V6Cr4Mo4Zr) was studied in detail. Electron back scattered diffraction (EBSD) and optical microscopy was employed to investigate the deformation conditions on the microstructure. The effects of compression were indexed in terms of changes in lattice strain and stored energy. Significant increase in stored energy induced peak broadening at higher deformation. The increasing deformation dramatically increased the misorientation distribution. Texture evolution showed the changes in each stage in accordance to the mechanical properties of beta titanium alloy. Development of (111) plane are prominent at 75 percentage deformation in comparison to as-received condition. Simulated texture showed complete agreement with experimental results.

Keywords: Beta, Titanium alloy, Texture, EBSD, Stored energy, Simulation

Characterization of Additively Manufactured Aluminum Alloys using Ultrasonic-based Non-Destructive Testing technique

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An Ultrasound based C-scan Non-Destructive Testing (NDT) method is used to characterize three different additively manufactured (AM) aluminum alloys, AlSi10Mg, AlScMg, and Al20X, using the laser powder bed fusion technique. A-scan signals are collected at different locations on the component and used to calculate the time of flight (ToF) and the speed of sound in the material at various locations. The Young's modulus is evaluated via NDT technique. The porosity of the AM alloys with varying process parameters is evaluated using optical metallography and image analysis, while the apparent density is estimated using pycnometry. Young's modulus is evaluated using room temperature tensile testing, and the values of Young's modulus from C-Scan and tensile testing are correlated. A model is built based on the variability in the modulus with variable porosity in respective alloys to bring out the role of defects in AM alloys and the sensitivity of ultrasonic testing.

Iron-Nickel based Rare Earth Free Permanent Magnets

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Permanent magnets find wide-spread application in energy conversion, telecommunication, data storage etc. Rare earth (RE) based permanent magnets like Nd-Fe-B and Sm-Co cover the majority market share. Their increasing demand as well as depleting resources of RE could make these magnets economically inaccessible. This gives us the opportunity to indulge in research for finding new magnetic materials which can replace or strategically provide an alternative to RE based

permanent magnets. The key feature of an ideal permanent magnet is high energy product i.e. (BH)max value. Most of the RE magnets show high energy product value which occurs due to the magnetocrystalline anisotropy arising from the 4f electrons and high saturation magnetization caused by the presence of Fe, Ni and Co atoms having high magnetic moments. Thus, it is extremely difficult to develop a magnetic material with large (BH)max without exploiting the prime source of anisotropy i.e. 4f electrons.

Here, L10 FeNi (tetrataenite) is discussed as one of the most suitable candidates for future permanent magnetic material. L10 FeNi has drawn the attention of the scientific community for the theoretically predicted high value of (BH)max, abundant availability of constituent elements (Fe, Ni) and its existence in natural meteorites. Although L10 FeNi has shown immense potential for application in permanent magnets due to its high magnetocrytalline anisotropy and magnetic saturation, the bulk synthesis of this material is not yet achieved. The problems in laboratory synthesis of L10 FeNi and the technological limitations for practical use are dominated by the slow diffusion of Ni in the FeNi lattice around the low order-disorder temperature. The synthesis approach by non-equilibrium processing techniques to stabilize the ordered phase is studied in the present investigation.

Development of a Ring Tensile Test Technique for Small Diameter Tube

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The mechanical properties of tubular components in transverse direction are evaluated by ring tensile test (RTT). While the procedures for testing of large diameter tubes (diameter > 150 mm) are well established and codified, studies on transverse properties of small diameter tubes by RTT are very limited. RTT is very promising for application to cladding tubes of fast reactors (6-8 mm in diameter) in situations where the volume available for testing irradiated tubes is limited or when directional properties encountered in some products (e.g. ODS steels) are to be evaluated.

In the present work, tensile testing of transverse ring specimens of cladding tube (6.6 mm outer diameter and 0.45 mm wall thickness) is reported. Tensile specimens of gage length 2.0 mm and gage width 1.0 mm were carved in the transverse direction using wire EDM and subjected to tensile loading using specially designed mandrels, with Digital Image Correlation (DIC) technique for strain measurements. Finite Element Analysis has been carried out to examine the effect of

specimen geometry and friction between the specimen-mandrel on the deformation behaviour. The presentation will cover design and development of ring tensile testing, FE analysis, and the comparison of the results of simulation and experiments for two steels namely alloy D9 (modified AISI 316) and Modified 9Cr-1Mo.

Keywords: Ring Tensile Test (RTT), Load-displacement curve, Friction, DIC

Interdiffusion Study in β –(Ni,Pt)Al Bond Coat System

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Interdiffusion analysis in multicomponent alloy systems plays a pivotal role in controlling various processes and in designing materials. Interdiffusion of elements also leads to changes in microstructure and properties during service, especially for the material operating at elevated temperatures. The urge of increasing efficiency of gas turbine engines has led to higher service temperatures and longer life by the application of thermal barrier coatings (TBC) on Ni based superalloys. To prevent oxidation damage to the superalloy substrate, bond coats are used in which diffusion acts as a key factor influencing the stability and durability of the engine components. β-(Ni,Pt)Al coatings have been widely used as bond coat materials over the past few decades as addition of Pt improves oxidation resistance by accelerating diffusion of Al to form a continuously growing TGO (thermally grown oxide) layer. However, this also stimulates interdiffusion of Ni and Al between bond coat and substrate causing degradation of TBC system. Hence, it is necessary to get a clear understanding of diffusion behavior in β-(Ni,Pt)Al system. Knowledge on the interdiffusion coefficients would not only help in predicting the kinetics of diffusing elements but also manifest the effect of one component over the diffusion of another. In the present study, ternary interdiffusion coefficients are evaluated in β-(Ni,Pt)Al at 1100 ^{0}C cover wide range of compositions by employing Kirkaldy's approach. Diagonal diffusion couples are prepared in β region of Ni-Pt-Al alloy to minimize the uncertainty in determining ternary interdiffusivities. Effect of Pt on interdiffusion of Ni and Al is analyzed from the cross interdiffusion coefficients.

Development of Highly Durable Superhydrophobic Coating by One Step Plasma Spray Methodology

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In the current investigation, the mechanical, chemical and thermal damages on the blades of a compressor used in the aerospace engine have been tried to minimize by developing a superhydrophobic coating on the blade surface. In the absence of any information in open literature, for the fabrication of the coating, one step plasma spray process was implemented. For this, a well-mixed powder ($Ni_{55}Ti_{45}$ (wt %)) of Ni and Ti was used. The analysis of SEM, XRD, hardness and roughness of the coated sample favours the theory of superhydrophobicity and it is ensured from the measured contact (165º) and sliding angle (8 ± 1º). The adhesion test assures high force of adhesion at the interface and the achieved value indicates that the failure limit (40.85 MPa) of the developed coating is very high in comparison with the others. Furthermore, the abrasion resistance test depicts excellent abrasion resistance. These two investigations indicate that the mechanical durability of the coating is very high. The thermal annealing of the coating is also very high (400 ºC) and beyond this temperature (600 and 900 ºC), the superhydrophobic characteristic changes hydrophobic. The above stated behaviour ensures excellent thermal stability of the coating. For the chemical stability quantification, pH and corrosion tests were perfomed. The coating retains its suprhydrophobic property in the range of pH (9.5 to 2.4) and beyond this at pH=10 and pH=2 the obtained contact angles are 138˚ and 143˚ respectively. In addition to the above, the coating depicts better corrosion resistance in comparison with substrate and also coating developed by using other technique.

Industry 4.0

KEYNOTE LECTURES

Whether AI: Artificial or Augmented Intelligence? Can we do more?

Ravi Gudi
IIT Bombay

AI and ML based approaches to reconstruction and prediction, with a view to assist decision making, have re-emerged with a stronger potential and application spectrum. These approaches have relied quite heavily on the power of modelling tools, both statistical as well as other advanced AI based tools.
However, in any decision making, there are considerations related to credibility and completeness of the information sources, which can additionally be brought in, to help in the AI and ML based modelling approaches. This talk will explore such possibilities and pose (perhaps awkward) questions on the adequacy of AI and ML approaches as they exist today. The talk will motivate alternate complementing modelling paradigms that may help to generate a relatively accurate reconstruction and prediction with a view to improved decision making. Illustrative examples in chemical engineering from industrial as well as academic literature will seek to reinforce some of the proposed ideas.

Implementing Industry 4.0 & Beyond

Raghudeep Madineni

DGM, Digital Manufacturing Lead, Ather Energy

"Do we need to embark on the Industry 4.0 journey?", is no longer a question now in the Industry. It is only the matter of figuring out the HOW! Early adopters of the Industry 4.0 revolution who have mastered this 'HOW' are reaping the benefits now. This was obvious during the recent challenges of limited people at the workplace. It has catapulted a strong need in the manufacturing ecosystem to bring in digital transformation as a need now. On the other hand, Customer centric I4.0 organizations have recognised the need to ensure quick delivery to the customer with the use of technology across the value chain.
A key aspect is Data! Architecture should support capturing the right data from the shop floor, IT-OT layer to integrate and manage data, smart applications to convert data to information for various users in the organization value chain.
The most challenging phase of the Industry 4.0 journey is "Implementation". It involves collaboration with people across functions, understanding the key goals, adapting to the culture of

the organization, understanding existing systems and finally the technology and solution partners who support in the journey.

"Implementing Industry 4.0 & beyond" - this talk gives you insights on unlocking the power of data and approach for Industry 4.0 Implementation.

A New Data/AI Platform for Accelerated Materials Innovation

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The ambitious goals of Industry 4.0 demand the deployment of a versatile end-to-end enterprise software platform that can support all the data management and AI/ML (artificial intelligence/machine learning) needs of a multidisciplinary team comprising designers, manufacturers, and material science experts. Such a platform should serve as the essential *glue* connecting the domain experts with their data assets and compute resources. It should aggregate, curate, and disseminate digital artifacts and assets, which might include a broad variety of datasets, AI/ML models, and workflows. It should meet the FAIR (findable, accessible, interoperable, reproducible) standards and comply with all applicable security mandates. The central impediments come from (i) the large and continuously evolving variety of materials research data (resulting from ongoing advances in multi-resolution experiments and physics-based multi-scale simulations) hindering the design and adoption of standardized data models, (ii) lack of adequate customization of general-purpose data management infrastructure to problems in materials discovery and deployment, and (iii) the many practical difficulties encountered in assembling and directing cross-disciplinary teams of domain experts (from materials science, mechanics, and manufacturing communities) and computer scientists to design and deploy UI/UX (user interfaces/user experience) tools needed for fast and easy adoption. The recently launched commercial software platform called MIND was designed to address this critical gap. The unique features of the MIND platform will be discussed in this talk.

Importance of Data and AI in Manufacturing Ecosystem

Manas Agarwal
CEO & Co-Founder, Affine Analytics

Analytics is essentially an act of collecting and manipulating data to uncover business and operational insights. Manufacturing environment has various moving parts: People, Machines, logistics, Materials, Produce and ever-changing consumer demands. Data is created at every turn but is often not easily accessible and needs to be contextualized for business consumption. With analytics services stack, manufacturers can quickly evangelize data from factory floor and set it up for business consumption through reports, dashboards, and analysis.
High uncertainty and low growth have forced manufacturers to squeeze every asset to maximum level. The next target is their own data for generating value and bringing out efficiencies across business value chain and shop floor. Analytics is foundation of Industry 4.0. A wide range of industries are coming to understand this is the way we must do business to be successful and to stay competitive in this new world of technology. Manufacturers empowered with analytics can reduce process flaws, saving time and money. Data Intelligence evolution in context of IR 4.0 from convergence of OT-IT to IIoT and further Cloud and finally moving to Edge Computing. Analytics to AI in Manufacturing caters to different functions like Operational Excellence, QMS, PdM, Supply Chain, Process optimization etc.
Operation executives can use analytics to deep dive into historical process data, detect patterns and relationships among process steps and inputs, and then optimize the variables and factors that prove to have the highest impact on yield. Many industries now have an abundance of real-time shop-floor data and the capability to conduct such sophisticated statistical analysis. They are taking previously silo data sets, aggregating them, joining them, and analysing to uncover important insights.
Today's Manufacturing Analytics must be understood as the "era of data-enriched offerings". Business Models need to evolve to harness the creation, delivery, and capture of currently unexploited forms of value. Business Models in the era of Industry 4.0 must "be designed around customer centricity, value creation networks and the data that is generated". A new Business Model must create value to customers beyond the product itself and generate profits throughout its life cycle.

Keywords: Manufacturing, industry 4.0, machines, factory floor, analytics

Hybrid Digital Twins – The Role of Physics Informed Machine Learning

Shrinivasa Mohan
Ansys

In this talk we will discuss the importance of models in improving the quality of insights generated from data. We will highlight the challenges in building fast and predictive models and discuss how models built on a physics-only or data-only approach cannot match the demands of a digital twin. We will show how physics informed machine learning models, built synergistically with *a priori* physics and design principles, and empirical information available from testing and operations, combined using the framework of machine learning can satisfy the needs of digital twins. We will demonstrate the effectiveness of this approach using examples.

Application of AI lifts Quality Control to the Next Level

Lucas Corts
Head of Business Development at Smart Steel Technologies

Substantial performance improvements in quality, energy efficiency, productivity and delivery reliability is described as the goals of AI use in the steel sector. Steel manufacturers are justifiably sceptical. The process chains are extremely complex. In the past, AI approaches have failed due to lack of process expertise. Currently, there are many AI pilot trials with fluctuating levels and only a few successful AI projects that have actually led to drastic improvements in production. Positive examples with substance are the optimization of surface quality for Automotive Exposed and other grades achieved in 2020 by Smart Steel Technologies through automated, AI-supported continuous casting optimization and AI-supported temperature control in the liquid phase. The central theme in 2021 is the transformation from AI-based individual optimizations to end-to-end AI-supported production from ore to galvanized coil. This systematic implementation of AI increases productivity, quality and makes the entire process chain more flexible. The presentation will use specific projects to show how Smart Steel Technologies is supporting leading steel producers in this transformation.

Digitalization for Advanced Steel Manufacturing through Simulation, Visualization and Machine Learning

Chenn Zhou
NIPSCO Distinguished Professor of Engineering Simulation
Director, Steel Manufacturing Simulation and Visualization Consortium (SMSVC)
Director, Center for Innovation through Visualization and Simulation (CIVS)
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Computer simulation, visualization and machine learning are increasingly playing key roles in the Digitalization for advanced steel manufacturing. These technologies can be used to create cutting-edge physics-based and data-driven tools for real-time decision making to address critical issues related to energy efficiency, carbon-footprint and other pollutant emissions, productivity, quality, operation efficiency, maintenance, and more. These technologies can provide fundamental understating and practical guidance for process design, troubleshooting, and optimization, new process development and scale up, as well as workforce development. The Center for Innovation and Visualization through Simulation (CIVS) at Purdue University Northwest has used these technologies to develop and implement digitalization for Advanced Manufacturing in partnerships with steel and other industries. Methodologies and project examples will be presented in this paper.

Digitalization and Industry 4.0

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The fourth industrial revolution is well underway! The evolution is shaped by the many small changes leading collectively to an enormous change. New technologies require Total Solutions and Partnerships to be successful. How we define the products and its characteristics in the digital age have changed significantly. Products are getting personalized by means of individual preferences and short-term requests. To extend the technical performance and differentiation, companies are focusing on digital enrichment of products and services. By adding sensors, actuators, and embedded systems with the ability of data processing and autonomous communication, cyber-physical systems are created which act as a bridge between physical and digital world.

The Why of Industry 4.0 is now clear. Companies see great benefits it offers towards a sustainable future. The technology enablers for implementing Industry 4.0 are also well defined and there are deep research and offerings coming out from each of these areas. A common challenge for large and even medium-size organization is failing to adequately navigate the digital transformation an organization must go through. If an organization must capture the benefits of Industry 4.0, especially at scale, it is important to have a plan across divisions and/or functional groups.

Typically, in any large and established organization, we usually talk about a combination of Brownfield and Greenfield implementation. In both scenarios, be it Greenfield OR Brownfield building a scalable and efficient ecosystem is one of the main considerations. The different components of any implementation must be able to function independently and be managed independently. To realize the complete scale of deployment, the systems must work together as a whole than as individual components. Machine learning is an enabler of artificial intelligence and will play an increasingly significant role in Industry 4.0. Security requires heightened focus to protect against both known and unknown threats.

ORAL PRESENTATIONS

Fully Automatic Light up of Twin Shaft Lime Kiln

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Lime making is an important part of BOF steel-making process. Lime is added after the beginning of the oxygen "blow", where it reacts with impurities (primarily Silica) to form slag, which is later removed. There are 9 PFR (Parallel Flow Regenerative) lime kilns in Tata Steel, Jamshedpur producing 950 KT/year of lime to cater to the Quicklime requirement of Steel-making shops.
Light-up of heating unit has always been a pain point from safety point of view, be it Blast furnace stoves, Power plant or sinter plant or lime kiln. The conventional process has been to use fireballs (cloth soaked in oil and then ignited) to ignite a coke Ovens gas torch which raises the surrounding refractory lining temperature. This enables the heating unit to be fired with any other gas that is lesser combustible. But this process has always been fraught with safety issues mostly because of backfiring due to extinguishing of flame and then igniting without proper purging.
In this paper we discuss how we applied electric lighter powered with LPG (Liquified petroleum gas) to aid the fully automatic light up at our twin vertical shaft lime kiln. This LPG lighter is used to ignite the coke ovens gas torch (also called pilot burner). Flame sensors and gas regulating valves are used to ensure that in case pilot burner flame extinguishes, it does not result in gas entrapment. Feedback of sensors and soft commands allowed the operator to control the light-up process from the comfort of the control room.

Keywords: Lime kiln, Pilot Burner, Flame Sensor

Digital Transformation of Sinter Plant-III, Bhilai Steel Plant

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The advent of large-scale machine to machine communication and IIoT have enabled the ongoing automation of traditional manufacturing and industrial practices with introduction of smart machines, powered by increased automation, improved communication, and self-monitoring, enabling analysis, diagnosis and decision making, without the need for human intervention.
Bhilai Steel Plant, flagship unit of Steel Authority of India Limited has recognized the importance of digital transformation and has forayed into the I4.0 world with a multi-pronged approach of Start, Scale and Sustain with pilot projects implemented in different shops, with the primary focus on machine connectivity and data analytics.
Sinter Plant-III, a vital cog in the production chain, has taken many initiatives for the implementation of DX initiatives, with an aim of improving the safety, reliability, and productivity, thereby maximizing the value of existing infrastructure with savings in energy, time, and manpower costs.
One major project identified and to be implemented in SP-III is the Digital Twin of Sinter Machine. The various conceptual and pragmatic definitions of Digital Twin and Cyber Physical Systems are discussed. The issues and resolutions in the various steps involved in the creation of a DT framework are also explained including developing meaningful co-relations from the stochastically non-linear processes, seamless integration of data between application islands and data silos, developing proper predictive algorithms and data models, enabling higher optimization level across equipment/sub-process level.
The underlying idea is to implement smart sensorization and useful APIs to leverage the full potential of the digital twin framework. The deployment is still in the early stages/conceptual stage, and its full value will be realised and evaluated in the coming months. However, the initial learnings from the project including deep knowledge of operational/production processes, OT-IT convergence, collection and validation of data are also elucidated.
Furthermore, to enable the full potential of data driven prediction models, the analytics have to progressively evolve from descriptive and diagnostic to predictive and prescriptive. Hence, its

scope also expands from single asset monitoring to a fleet of assets. A number of other projects related to AI based predictive maintenance of critical equipment like IMCC/motors and mixer-nodulizer, smart fuel rate determination to reduce coke rate etc are also implemented/conceptualised in this direction.

This abstract pertains to the digital transformation journey of Sinter Plant-III, Bhilai Steel Plant by implementation of a Digital Twin for enhanced quality and productivity of sinter with improved safety and reliability of the overall system.

Innovative Wireless Technology in SAIL Plants: Recent Efforts & Future Applications

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The major concern of the steel industry in the present scenario is to increase productivity of man and machine. The automation of machine in steel plants based on transfer of signals through use of wireless technology provide an apt solution in vast area such as raw material handling area where manpower deployed is difficult and also in hazardous area subject to high temperature such as blast furnace and steel melting shops. The use of wireless technology in the steel industry has a significant impact on throughput and safety of the manpower.

Research & Development Centre for Iron & Steel, Ranchi, has designed and implemented several automation schemes using wireless technology in SAIL Steel Plant as per shop logistics. The application of this system ranges from raw materials handling plant to blast furnace and steel melting shop.

The use of wireless based system has circumvented the problem related to requirement of long-distance signal cable, deployment of manpower in remote and hazardous area and difficulties arises in fault diagnostic. Through wireless transmission of signal, it has become possible to remotely control and monitor moving stacker-cum-reclaimer in vast raw material handling area, remotely operate the mud gun operations in blast furnace and turret in steel melting shop.

This paper describes some of the unique control innovations which have been conceptualized and implemented in SAIL Steel plants. The systems based on variety of wireless technology demonstrate ingenious designs to customize for unique applications and also interface with controls of the process lines. These implemented systems have enabled significant improvement in productivity of the concerned shops through reduction in operational delays as well as reduction in manpower requirement.

In terms of growing competition in the market, wireless technologies have become more important to improve the overall sustainability and competitiveness of the Steel Plants through increase in productivity of man and machine.

Keywords: Stacker-cum-reclaimer, wireless signal transmission, productivity

Winning Customer Trust through End to End Optimization Modelling by Leveraging Data Science

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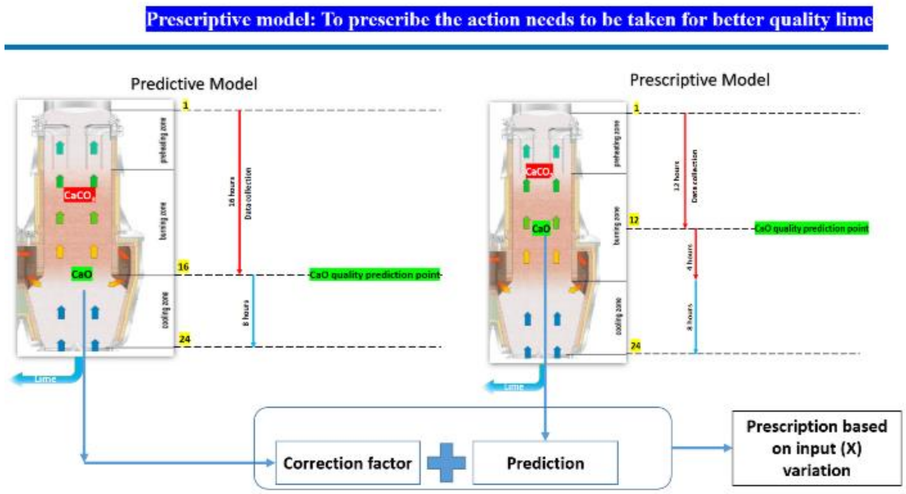
In BOF process at Steel-making shops, lime is added for silica and phosphorus removal, after the beginning of the oxygen "blow", where it reacts with impurities (primarily silica and phosphorus) to form slag, which is later removed. There are 9 PFR (Parallel Flow Regenerative) lime kilns in Tata Steel, Jamshedpur producing 950 KT/year of lime to cater to the quick lime requirement of steel-making shops, with stringent quality requirement of high available CaO content in lime.

The paper discusses the use of data Science in our endeavor to improve CaO content in lime and at the same time reduce fuel consumption. First an exhaustive list of causes that can be substantiated with data are prepared and narrowed down to 8 causes through correlation analysis. Linear regression on these highlights 4 prime causes that is responsible for 38% of the variation in the output i.e available CaO%. Statistical design of experiment is performed on these factors to find their optimum range. Simultaneously a need was felt to quicken the product analysis cycle as it took 8 hours for the chemical analysis to come. This led us to develop a quality predictive model based on the last 24 hours of kiln data. There was an effective reduction in Product to analysis cycle by 8 hours. After achieving above 90% strike rate of prediction with the actual, it was perceived that there was scope of further reduction in the analysis time by 8 hours which shall enable the operator to take pre-emptive action. As there is no chemical reaction in the cooling

zone, quality prediction is done on the basis of only 16 hours data and prompting the operator to correct the deviating parameter. This exercise led significant improvement in the available CaO% in lime from 91.6% to 94%.



To ensure the customer that sustainability cannot be compromised with quality, simultaneous reduction in fuel consumption is of utmost importance. Running parameters of Lime Kilns are analyzed with respect to heat consumption and quality of lime produced. In absence of any strong correlation between input parameters and heat consumption, a novel technique of grouping of data into good and bad zones were employed to get the optimum range for kiln parameters. Kilns that are Twin shaft vertical PFR were run within the range provided by the model under the same production rate. Data during the trial period shows that there was significant reduction in heat consumed per kg of product. At the same time a decrease in heat loss from waste gas temperature and Lime heat is also seen. This is a good example of Nonlinear regression optimization technique application in a heating unit having long gestation period.

Keywords: Lime kiln, Fuel optimization, Lime Making, Prescription model

Dynamic Online Estimation of Chaos Control Parameters from Process Data of a High Temperature Chemical Reaction System

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The development of and implementation of technology for online control of chaotic dynamical systems is gradually catching up in metallurgical industry too. The conventional models based on physico-chemical principles, developed so far, are not successful in such processes. The analysis of high temperature processes data of BOF and sponge iron rotary kiln has been carried out. It is confirmed that these processes actually belong to the class of chaotic dynamical systems. The results of tests of Lyapunov exponent and 0-1 test of chaos will be presented to confirm the same.

In a chaotic dynamical system, only short-range predictions are possible. Therefore, for control purposes, it is important to extract the chaos control parameters dynamically, at short intervals of time. This allows the processes to be controlled efficiently, to make them follow the desired trajectory, up to the end point. Two methods of dynamic parameter extraction from chaotic systems have been tested and will be presented. We first demonstrate their application to stabilization of fixed point in a logistic map. Then it is shown that they can be easily extended to stabilize a k-periodic orbits in complex chaotic dynamical systems. It is important to know that chaotic dynamical systems, as opposed to usual thinking that they are random, are predictable.

Analysis of actual plant data of BOF and rotary sponge iron kilns is carried out and results are presented.

Computer Vision Based Machine Learning (CVML) Technology to Enhance Production in Steel Melting Shop

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JSW Steel Ltd, Dolvi Works is India’s first to adopt a combination of Conarc Technology for primary steelmaking, aiding the production of hot rolled coils. In the current era of digitalization around the globe, CV/ML based projects are less in number in the hardcore manufacturing domain.

In JSW, we have started using CV/ML based approach in Dolvi. To meet the increasing demand for liquid steel by reducing processing time, we collected relevant quantitative data and identified the key bottlenecks such as micro activities in setup duration of Primary Steel Making at Steel melting shop. Variability is a key characteristic for evaluating the performance of a process. Small variability for a Setup duration of a heat can generate high production variability. Reduction in

Setup duration variation are imperative for increasing throughput. This Project aims to monitor the Setup duration micro activities by using advanced automated camera vision with Machine learning technology. Furthermore, it provides real time visual representation of current heat and Comparative study of historical heats. The computer-based ML can be used without any manual intervention to identify hidden delays and then take Corrective action to remove the delays, unplanned activities and it results enhancing the production. Hence, this paper represents how CV/ML based project helps organization to eliminate the bottleneck at micro level in steel melting shop and enhance the overall SMS Productivity.

Keywords: Digital Transformation, Digitalization, Micro activity, CV/ML, Steel Melting Shop

Steel Ladle Life Prediction Model Building by Optimising Operating Parameters

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Operating parameters have immense impact on the performance of the steel ladle refractory materials. Various operating parameters had been used for the model building for steel ladle refractory life. Optimising the operating parameters through the digital model building will help us to enhance the performance of the steel ladle. We have analysed all the critical and non-critical operating parameters for the steel melting shop for steel ladle applications. We have taken few assumptions such as quality of refractory variation is very low among the various suppliers. Various parameters study is performed to get the insights of the operating parameters. The suitable model built with the help of various analytics tools. We would find out the suitable equation for the steel ladle life predictions with the parameters.

The objective with the study finally leads to the performance improvement of the steel ladle life by 5 to 10 heats per steel ladle. The financial benefits through the insights generation for the study are comparatively high. The further study with the critical parameters will be done for more scientific work in those fields.

Galvanyes: Unique Model to Improve Surface Quality in Continuously Galvanised Product

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Flat-rolled steel producers are facing a demand towards zero-defect tolerances regarding surface and shape quality. This strict requirement is now becoming the standard for the whole steel industry products spanning from automotive, appliances to construction segment. In recent past, automotive customers of hot dip galvanized [GI] and galvannealed [GA] steels have become more and more demanding regarding surface quality. The quality of surface coating is dictated by tight control of process parameters of zinc-bath e.g. temperature, concentration of aluminium and iron. Any deviation in the above-mentioned parameters brings unwanted product like dross. A good bath management aims at minimum variation in bath temperature and aluminium content plays a vital role in reducing the amount of dross generation in the bath.
The use of fundamental model for bath management [% Aluminium, % Iron, Temperature, etc] using online process data can play an important role in controlling the process parameters leading to minimization of dross. A prescriptive model for aluminium control and ingot charging was developed in this study. This model has multiple sub models e.g. dross kinetics, pot history, ingot charging, scheduling and all these sub models have been integrated into a single dynamic toolbox.
The model has been deployed at Continuous Galvanising Line #2 of Tata Steel for providing guidelines for addition of ingots (Zn, Zn-Al) and control of bath process parameters e.g. Al, Fe and Temperature. Prior to this model, addition of ingots in the bath was based on lab data for Al and Fe measured every four hours and operators experience. This tool predicts the Al (%) in the bath in real time and recommends a quantitative number of ingots to be charged to maintain the bath chemistry in defined working regime.

Identification of Short Rebars on Sorting Table using Novel Image Processing Technique

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Tata TISCON, a flagship TMT rebar brand, is manufactured at New Bar Mill for the construction industry of different geographies. Currently, manual inspection is performed to ensure rebars of correct length are bundled for customer and short length rebars are discarded. There are instances when short rebars get shipped due to human errors. This leads to rejection of bundle by customer and denting brand image of TISCON. For the first time in industry, an innovative machine vision system has been developed to automatically detect short length rebars and intimate operator so that removal of short rebars is ensured before bundling, leading to enhanced customer delight and improved brand value.

Thermo Mechanically Treated (TMT) rebars of different grades with qualities such as corrosion, seismic resistant and high strength carbon alloys are manufactured in New Bar Mill. Steel billets are rolled to form 72-meter-long rebars which are later cut to 12-meter length using a shearing machine. As part of this shearing process, in some cases, short bars are created which are less than 12 meters in length. After shearing, batches of 30-50 rebars move to a sorting table for quality inspection. An operator glances through the laid out rebars for any short length rebar (less than 12 meter) and discards it. Finally, they are passed on for bundling. On several occasions, it was found that short rebars go unnoticed during inspection due to human-errors and reaches the customer which are then rejected. A system to validate the removal of short bars before bundling is nonexistent in the industry. So, for the first time in the steel industry, an innovative machine vision system along with custom image processing algorithms and software capable of detecting and locating short rebars on the sorting table has been developed. It consists of two industrial grade cameras located strategically along the periphery of sorting table to capture an image of rebars. The cameras are triggered by signals generated in sync with movement of rebars from shear cutter to sorting table. This image is utilized by our novel image processing algorithm. Differentiating steel rebars from steel sorting table and rollers in an image was a pivotal challenge to detect the short rebars automatically. Our system guides the operator by providing a top view of table with virtual overlay markers on the location of detected short rebars and aid him to swiftly pickup and

discard them. Our innovation provides crucial verification of elimination of short length rebars from the process thus reducing the rejection of bundles by customer.

Keywords: TMT Rebars, Short length rebar, Image processing, defect detection, image segmentation

To Estimate the Energy Consumption of CONARC® Taking into Account Feed Mix Properties using Statistical Modelling

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To meet the ever-increasing demand for steel consumption due to the development of infrastructure, automobile, appliances and also to cut down the CO_2 emissions, there is a focus on development of energy efficient steel making processes. And one such process developed is CONARC® steelmaking route. The aim of development of this process is to extract the benefits of both the conventional top blown converter steel making and electric steel making (EAF). Since the steel making is an energy intensive process, and the electrical energy consumption accounts for 9% of the production cost, to make the process more energy efficient, attempts have been made to bring down the energy by optimizing the feed mix. To do this data driven statistical modelling is used as a method to extract the information from the historical data. A physiochemical model based on heat and mass balance is developed and validated using plant data collected from JSW Steel Dolvi. Having found out the relevant input variables Machine learning algorithm i.e. Multivariable linear regression (MLR), Decision Tree (DT), Random Forest (RF) and Support Vector Machine (SVM) are used for the prediction of energy. Out of these four algorithms used, Random Forest gives the best accuracy for the prediction with mean absolute error (MAE) of 0.39 having 100 number of trees. Random forest and SVM were further tuned using boosting method XGBoost and grid search respectively to improve the prediction accuracy.

Keywords: Conarc® Furnace, Physiochemical Modelling, ML Modelling, Multi Variable Linear Regression, Decision Tree, Random Forest, Support Vector Machine

Prevention of Rank-A Customer Complaints through Use of Digital Signature of Mill Process Parameters

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Tata Steel, India's Wire Rod Mill at Jamshepur, Jharkhand, produces wire-rods and thermo-mechanically treated re-bars (TMT rebars) in coil form through hot rolling of billets. The wire-rod coils are used by the downstream wire drawing processes for producing wires and subsequently for varied end applications like springs, reinforcement strands, wire ropes, welding electrodes, fencing wires, etc. The TMT rebars are used for reinforcement of the concrete structures. If any unintended grade of wire rod or TMT rebars reaches the customer, it would get processed in an abnormal manner and lead to major process disruption at the customer premises and more importantly can cause a serious injury during processing or even end use. Such cases of wrong supplies are called Rank-A complaints and viewed very seriously both by the customers and Tata Steel, as these cause severe brand erosion.

Hence, there is an effort to ensure that such Rank-A complaints are eliminated, and no wrong material is dispatched to the customers. One of the practices in force to detect any sort of mix-up is the use of eddy-current based sorters to compare the samples of the coils being produced against a known standard and destructively test any outliers to confirm mix-up. This is a manual process and fraught with the danger of sample mix-up due to identity loss. To overcome this challenge, mill signatures are used to detect a mix-up or confirm a planned change of product. To accomplish this, the motor current of the finishing mill (called No Twist Mill) is tracked on a time series and if there is a change beyond a threshold with no visible gaps of a planned product change, alerts are generated to caution the production and QA teams to conduct further checks on the affected coils to confirm if any mix-up has occurred.

This use of digital signatures is an additional barrier put up by Tata Steel in its Quality Assurance process apart from the grade sorter checks and the use of bar code scanning of labels on the coils to avoid the Rank-A customer complaints and enhance customer satisfaction.

Keywords: wire-rods, rebars, mix-up, signatures, motor current

Defect Detection in Production Line using AI Computer Vision Model

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Production Line for any manufacturing industry is very critical. Identifying the quality defects early, quickly and consistently during production will save costs for an organization (quantifiable and unmeasurable). For Fem-care products identifying defect during the process will save companies lot of cost by avoiding rejection by quality team at the end of the process. Machine Vision can detect defects/faults during the production of the product which can accurately identify defects from the live camera feed.

Developed a Deep learning-based Object Detection Model (YOLO, SSD etc.) to detect whether product has defect or not. Model is trained with the labeled dataset by Labeling of each image for each defect type (Tear, Contamination, Wrinkle etc.). Labeling involves drawing 'bounding boxes' around each defect in the images. Model trained on images to detect Contamination, Top Sheet (TS) and Secondary Top Sheet (STS) defects. The defects are further categorized as acceptable and unacceptable.

AI Solution using Computer Vision has been deployed to the production, the system will replace manual defect detection with a Deep Learning model that can detect at 98-99% accuracy.

Keywords: Machine Vision, Quality management, Defect Detection, Production line

Dynamix Model to Optimize Hot metal in Steel Melting Shop

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JSW Steel Ltd, Dolvi Works is India's first to adopt a combination of Conarc Technology for primary steelmaking, aiding the production of hot rolled coils. In the current era of digitalization around the globe, Machine learning based projects are less in number in the hardcore manufacturing domain.
At JSW, we have implemented Dynamix Model. With multiple process types available as well as feasible in Dolvi SMS I, there is high flexibility in terms of heat charge mix, i.e. Hot metal/heat as well as process type mix, i.e. with or without arcing. With variation in availability of Hot metal as well as shell availability on a day-to-day basis, dynamic planning and optimal use of resources becomes highly relevant in current time Moreover, large setoff process parameters also affect the number of heats such as available power & blow rates, scrap feasibility, planned downtime across shells, etc.
In consideration of this, Dynamix model is developed taking into account exhaustive set of variations for equipment and material availability, and providing the most optimal combination of heat-wise process mix and hot metal distribution across the shells for all range of available Hot metal supply from Blast Furnace.

Keywords: Dynamix model, Digitalization, SMS1

Coal Blend Optimization and Simulation using Machine Learning to Predict Coke Quality

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Coal is a raw material and plays very important role in coke making process. 4 to 5 coals are blended to produce coke. The developed model is based on coal properties and process parameters. Coal blend optimization model is developed based on linear programming using solver and Time Series model is developed for Coke Strength After Reaction (CSR) Prediction in the coke plant. The model takes the optimized coal properties as input with the process parameters and predicts the Coke CSR on daily basis, based on historical data and it's also able to predict CSR for change in coal blend to be used in coke plant, coal properties vary between different types of coal. Total input parameters to model are 28, out of which 7 parameters are for coal properties. Plant can act also based on model predicted value and identified operating range for critical variables to control the quality of Coke, using this approach coke plant is able to produce more coke with stable CSR.

The study shows that the Predicted CSR and Actual CSR were much closer proximity. Accuracy with test data is almost at same level of training data. Model is running in tandem with Optimization and machine learning both together. Model is getting retrained daily including data of previous day.

Keywords: Coal Blending, Linear Programming, Time Series, CSR

A Proven Technology to Measure Path of Burden Trajectory falling from Rotary Chute of Bell Less Top System in Blast Furnace

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Modern blast furnaces are mostly equipped with bell less top burden distribution systems. Bell less type burden distribution systems follow a burden matrix, which is specially designed to achieve desired top burden profile. The burden matrix is tabular data that represents a set of chute tilt positions with the corresponding number of revolutions required. Burden material flowing through different chute tilt positions possess a distinct trajectory path. Also, parameters like the geometry of the chute, the composition of ferrous burden (pellet, sinter and ore) affect the flow behaviour of burden material, which have a significant influence on the trajectory path of the falling material stream. It is impossible for an operator to select the chute tilt positions in the burden matrix, without measurement in a real environment. Tata Steel has developed a technology to measure the burden trajectory path in a real blast furnace environment. It is a rugged mechanical probe integrated with a high-speed data acquisition unit. A carefully designed standard operating procedures to safely conduct the measurement in hostile conditions of the blast furnace are developed. More than 10 years of rich experience of research professionals in the use of this technology for blast furnaces in Tata Steel has evolved the safety and accuracy of this measurement system.

Machine Learning Techniques for Fractographic Analysis

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Fractographic analysis, an important industrial and research problem, helps understand the cause of the fracture and modify the mechanical processing parameters for material property enhancement. Fractographic analysis requires a high skill level to clearly identify the fracture type and then deduce the reasons for failure. However, owing to the large volume of fractures to be analyzed in industries, it is sometimes performed by personnel with varying skill levels. Hence, the reliability of results becomes a variable of expert skill level, experience, focus while working, etc. Quantitative fractography is even more time-consuming and prone to errors. In this work, we try to overcome most of these limitations by computer vision methods. We address the problems of qualitative (classification) and quantitative (segmentation) fractographic analysis of additively manufactured Ti-6Al-4V alloy samples that failed under quasi-static loading conditions. We explore ways to build and inflate the size of the datasets while minimizing manual effort. We compare and analyze the results of models built using different approaches and identify the best approach which can deal with constraints on the dataset size, high inter-class and low intra-class variations in fracture modes. The results obtained from the developed models are on par or better than the experts in several cases.

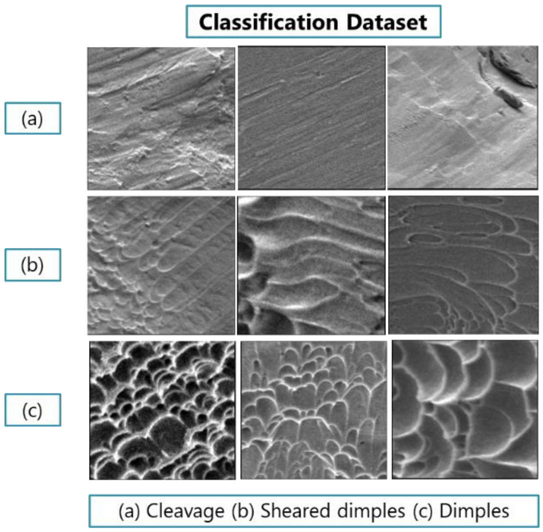

Fig. 1 Fractographic classification dataset

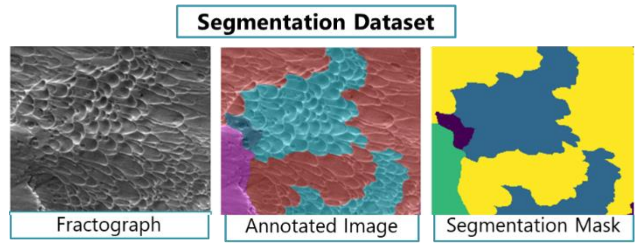

Fig. 2 Fractographic segmentation dataset

Keywords: Fractography; Classification; Segmentation; Additively manufactured Ti-6Al-4V

POSTER PRESENTATIONS

BOF End Point Predictive Model using Machine Learning

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Oxygen steel making processes are very complex in nature and composition and temperature of steel bath can't be measured continuously and operation conditions vary frequently, which makes it difficult to control the BOF end-point bath precisely. Thus, prediction tools are needed which can act as a guideline to control them. Various modelling techniques have been adopted in order to develop good prediction models. These models could be fundamental in nature based upon physical and chemical laws of the process on one hand and empirical approach on the other hand. Subject to the condition that there could be lot of variations due to error in input measurements and other uncertain factors beyond control, the actual process will always have some degree of uncertainty. Therefore, models which are based upon actual plant data are more reliable as compared to the fundamental models.

Machine learning algorithms build a model based on sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to do so.

In this study, a DNN regressor tool, Linear regression and decision tree regression was applied on a dataset having records of 1708 heats taken from SMS, DSP. From the dataset 1000 heats were taken for training purpose and 320 heats for validation and 79 heats for testing purpose. The dataset contained 15 input parameters namely Scrap wt, hot metal composition and weight, blow duration, Slag basicity and FeO and the output parameter was taken as end temperature.

For the deep learning approach different set of hyperparameters and model configuration were applied to get the optimum results. The hyperparameters included learning rate, batch size, steps mainly and the trained data was validated for ascertaining the model effectiveness.

The root mean square error (RMSE) for the DNN model, Linear regression and decision tree regression obtained were 29.02, 30.08, and 28.27. The low value of RMSE shows that the predicted values are quite near to the actual values thus giving good prediction ability.

Reducing Mill Operation Delay using Unsupervised Machine Learning Technique

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Hot rolling process carried out at New Bar Mill (NBM), Tata Steel consists of reheating billets to above recrystallization temperature followed by reduction of cross section in rolling mill and subsequent in line heat treatment and sizing of product length to customer length. The rolling process is carried out in mill stands grouped as Roughing followed by intermediate stands and then finishing mill. Here a very important parameter comes in picture is called the R-Factor. R-Factor is defined as the ratio of cross-sectional area of incoming stock to the cross-sectional area of outgoing area of a stand. By mass balance this is equal to speed of outgoing stock to the speed of incoming stock in a stand.

R Factor control in a continuous mill is very important to match speed of adjacent mill stands thereby achieving a constant mass flow through the mill as otherwise high tension can change the cross section of the bar making shape control difficult. R Fact or control is long rolling mill is traditionally controlled based on human judgement. With improvement in technology Tension and Loop Control systems have been developed which adjust R-factor to any speed mismatches between mill stands. Tension Control evaluates the torque changes and corrects the set speed relationships to achieve minimum tension in the rolled material. Loop Control evaluates the measured loop position, and automatically corrects R-Factor continuously along the billet, while keeping the loop position fixed to obtain the constant excess length. After every stand has rolled a certain tonnage, it is given wear compensation by reducing the roll-gap for the stand. During rolling it is important that R-Factor of lines post slitting should match. But with Loop Control under service and manual interventions made many times loop height becomes unstable. This also makes it difficult to control the nominal diameter of rebar and its weight tolerance, potentially causing mis-rolling cobbles or non-conforming product.

To eliminate this an artificial Intelligence based model has been developed which gives optimal parameters for mill setup based on data analysis of previous campaigns. The outcome of this is a set of five clusters for every section. Now the operators can choose the best cluster to operate the mill based on deviation of running R-Factors with those in the cluster and roll pass conditions for

each stand from historical data. The mill set up is then done accordingly by changing the R-Factor values in the system for mill stands and also the gap between the stands is adjusted to obtain area into out ratio to conform to the selected cluster.
It has been successfully implemented at New Bar Mill, Tata Steel and has led to increased availability of mill and also reduced human dependency.

Keywords: Hot Rolling, R-Factor, Artificial Intelligence, Tension control, Loop Control

Integrated New Product Development (INPD) System in Steel Manufacturing Division, Tata Steel

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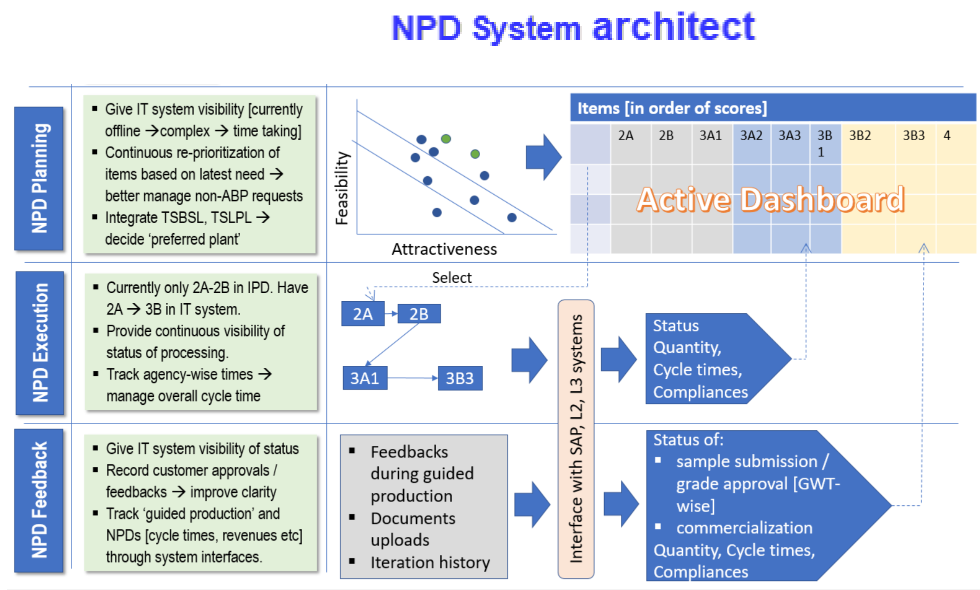
TSL steel manufacturing (Flat and Long product) is now diversified in different plants in India, therefore managing the new product development centrally becomes difficult. NPD activities start from capturing the requirements from customer and deliver the products to customers whose data is maintained in various IT platform (IPD, CMS, MES, SAP), therefore it is extremely difficult to track and control the cycle time, retrieval of documents and records, managing the records of production and sale after commercializing and management of different trial material, etc.
In order to become a customer-driven organization, TSL has implemented a standard process for new product development (NPD). The core of NPD process is a stage gate model that pre-describes the steps in developing an idea and converting it into a new product.
INPD system is extremely helpful to manage the long and flat product development portfolio and cross functional decision-making process. Key features of this system are:

- All steps of NPD will be visible to all stake holder for complete transparency
- NPD request will be qualifying as new product though system check. (Voice of customer and other document required at the time of request only)
- Technical feasibility and market attractiveness index will be integral part of the system and priority ranking calculated considering both automatically through system
- Head TG can manual override the ranking based on the Marketing demand / ABP NPD Workshop / MOM

- TDC no. Will be created at the time of trial and remain same even after commercialization.
- Real time activity dashboard.



Evolution of Integrated Margin Management in Reducing Flux Consumption in Iron Making

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Prediction of blast furnace's flux requirement is important which depends upon alumina load through raw materials. Carbonated flux like limestone, dolomite addition to blast furnace is undesirable due to calcination reactions leading to higher coke rate, slag volume and low productivity of blast furnaces. If all flux requirement of blast furnace is met through sinter, then there will be huge saving in terms of coke rate. Also, combination of flux uses in sinter making depends upon silica variation in iron ore fines that can be optimized to reduce overall flux cost.

This led to the requirement of advanced analytics driven model to meet both requirements of minimizing the flux cost and zero carbonated flux addition in Blast Furnaces.
Prediction of flux requirement has always been a challenge for blast furnace operators. Of late, there were applications of some excel based models in some blast furnaces. But they were not very effective in entire value chain starting from value-based sourcing of fluxes to final value-based uses of these fluxes during sinter and iron making. With availability of AIMMS (Advance Intelligent Mathematical Modelling System), it was embarked upon implementation of this innovation as this required optimization of large data which includes process, quality & plant constraints.
This paper illustrates how a complex supply value chain technical issue was resolved with the help of developing and implementation of advanced analytics driven model which is called Integrated Margin Management Model (IMM). Model predicts exact flux requirement beforehand based on future chemistry and tonnages of blast furnace raw materials burden. Based on this prediction and iron ore silica variation, model further optimizes fluxes and other raw materials addition to base mix for minimum raw material cost at sinter plants and minimum flux cost at blast furnace Iron Making.

Keywords: Integrated Margin Management Model (IMM), Sinter Making, Iron Making, Flux Cost

Phase Segmentation of the Ferrite-Pearlite Microstructure using Machine Learning

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Properties of steels are strongly dependent on the morphology of the phases present in their microstructures. Therefore, it is vital to segment the individual constituents of the microstructure accurately. Such a task is either done manually where the judgement can be subjective or through some standard image processing tools. Such processes are often unable to segment properly as it is based on simple convolution filters or using some threshold as the cut off. In this work, a computational Machine Learning model is implemented to segment ferrite and pearlite phases in SEM micrographs of hypoeutectoid steels. The SEM micrograph database for various steels were compiled. The ground truth was created for these SEM micrographs using

a moving window of appropriate size, which slides over the SEM micrograph and segments the pearlite and ferrite islands. These ground truth images were used to train a Random Forest (RF) Machine Learning algorithm. Random forest algorithm functions as classifiers by initializing a set of decision trees, for which the weights are allocated during training as per their proximity to the ground truth. We have devised an ensemble method in which the SEM micrograph features were extracted using different filters like Canny, Harris, Laplacian, Gabor, etc. Furthermore, the RF algorithm was implemented on the testing set assuming these filters as the decision trees. The RF model segmented the ferrite pearlite phase with the high degree of accuracy.

Availability Augmentation of Rebar Mill through Effective Alarms & Trip Logics based on High-speed Prescriptive Data Analysis

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New Bar Mill (NBM) plant of Tata Steel Ltd is prime manufacturer of Tata Tiscon branded products, which uses hot rolling process to convert billets into rebars. Billets are reheated in a reheating furnace and rolled into various sections. Bar Mill is constituting of Roughing Mill, Intermediate Mill, Forming Mill and Finishing Mill, where billet is converted in shapes to become rebar. New Bar Mill was commissioned in year 2005 at capability of 0.6 MTPA and over the time through various improvement initiatives, plant is currently operating at 1.05 MTPA.
With the increase in production & speed of NBM mill over past years had also increased the torque load in mill stands and drive gearboxes which had resulted in failure of stand and gearbox in recent past two years. Proposed paper describes what kind of logics are built in the drive system to avoid discharge of cold billet (below 1050 °C) from reheating furnace and generate alarm in case of torque goes beyond certain limits for few seconds for roughing mill stands and trip the mill stand #1 to stop the rolling if torque goes beyond the input torque limit of gearbox for even 1 second. Incorporation of newly made alarm and trip logic management system has enabled the operators to take better decision on controlling the rolling parameters.
This paper describes how process parameters itself can be used for enhancing the equipment reliability and availability of plant. Newly built alarms and trip logics have been tested in past 8

months at many instances and have been proved its worth. Incorporation of such logics is first of its kind in any steel plant rolling mill.

Keywords: Mill Drive, Gearbox Reliability, Torque, Cold Billet, Alarms & Logics, Iba System

Development of the Mobility Database for the bcc Phase of the Ti-Al-Mo Ternary Alloy System

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Beta Ti alloys are an important class of materials that finds its applications in aerospace, automobile and biomedical industries owing to its superior strength-to-weight ratio, formability and corrosion resistance. Among the different multicomponent beta Ti alloys like Ti-5553 and beta 21s, Ti-Al-Mo ternary alloy system is a prominent sub-system. Understanding of diffusional interactions among different components is a handy tool to model and develop prediction tools for kinetics of different diffusion driven-metallurgical processes like homogenization, eutectoid decomposition, nucleation, sintering and diffusion bonding. One direct approach to utilize the valuable information of experimentally evaluated interdiffusivities is the development of a mobility database. In the present work, mobility database has been developed for the bcc phase of Ti-Al-Mo alloy system.

Based upon the CALPHAD-like approach developed by Jonsson and Anderson, the mobilities of individual components i.e., Ti, Al and Mo for bcc phase of Ti-Al-Mo alloy system were expressed in terms of Redlich-Kister polynomials. An exhaustive compilation of experimental interdiffusivities of respective constituent binaries viz, Ti-Al, Ti-Mo and Al-Mo and ternary Ti-Al-Mo system for the bcc phase field was done. It was then utilized to optimize the mobility parameters for the bcc phase of binary Ti-Mo and Al-Mo and ternary Ti-Al-Mo systems. Data optimization was performed using PARROT module, a data optimization tool available within Thermocalc software. The compiled optimized mobility parameters constitute mobility database.

The mobility database so developed for the bcc phase of Ti-Al-Mo alloy system was utilized to evaluate interdiffusivities against experimental interdiffusivities available in the literature for the ternary system and was also utilized to simulate concentration profiles for experimental diffusion

couples. The optimized mobility parameters for the bcc phase in Ti-Al-Mo alloy system based upon this work can be directly utilized during mobility parameter optimizations for higher order systems having Ti-Al-Mo as a sub-system.

An Analytical Approach to Improve the Transfer-bar Thickness Accuracy

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Accurate transfer bar thickness is one of the important dimensional parameters for any roughing mill, although slight deviation is acceptable because that can be compensated later in the finishing mill. Because most of the modern hot strip mills do not use thickness measurement gauge in roughing mill (to minimize the overall cost), hence finishing mill setup is calculated by assuming that there is no deviation in the transfer bar thickness. Thus, excessive deviation in transfer bar thickness may cause some severe issues in the finishing mill e.g. excessive force and power requirement, width necking, instability, etc., and may result in cobble. The current study deals with the formulation of a linear regression-based model of machine learning techniques, to predict the optimum roll gap in a roughing mill pass. In this study, actual delivery thickness at each pass is numerically calculated based on actual roll force realization, which was found close to the manual measurements. A linear regression model is developed and trained on the pre-processed raw data, which has Coefficient of Determination (R^2), and Root Mean Square Error (RMSE) 0.98, and 0.41 mm, respectively. Finally, an optimum roll gap offset matrix was prepared and implemented in the last pass of roughing mill at TATA Steel, Kalinganagar. In the first phase of implementation, the average transfer bar thickness error was approximately reduced, from 4% to 0%, and in the second phase, it came down up to -2%.

Keywords: Hot Strip Mill; transfer bar; liner regression; machine learning; optimum roll gap

Prediction of Iron Ore Pellet Properties using Random Forest Method based Statistical Model

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Cold compression strength (CCS), tumbler index (TI) and abrasive index (AI) are important strength parameters, to measure the quality of iron ore pellets. The dynamic nature of the process and variations in the feed of the pellet, make difficult to achieve the desired pellet properties, which are generally measured after completion of the process. Statistical model facilitates the real-time prediction of the properties with greater accuracy. A property predictive model using random forest method (a widely used machine learning technique) has been developed for online prediction of the pellet properties. An optimum combination of 22 input parameters including iron ore concentrate chemistry, size distribution, Feed Blaine number, specific waste consumptions, pellet moisture, green compressive strength, drop strength, induration machine parameters viz. feed rate, machine speed, firing temperature, burn through temperature (BTT), down recuperation temperature (DRT) etc. were selected for the model development. The coefficient of determination (R^2) and mean absolute error (MAE) of the model is found 0.75 and 1.76 respectively. The model has been implemented in Pellet plant and the predicted values of strength properties are found very close to the actual properties with error less than 5%. The model is running successfully and helps operators in optimizing the process parameters to achieve the desires pellet properties.

Monitoring of Steelmaking and Casting Equipment through Heat Map

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Equipment health is of utmost importance in steelmaking and casting process. Any equipment not performing well can lead to production and quality losses in the shop. In this work, all equipment from Steelmaking and casting process was considered and sub-equipment was identified. All sub-equipment which was highly critical for quality were tracked on weekly basis

in the form of heat (green, yellow, red). This helped in identifying the issues and taking corrective actions beforehand. This was a step towards Industry 4.0 for improving steel quality.

A Superior Laser based Top Burden Surface Measurement Technology for Blast Furnace

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Burden distribution dictates the gas flow patterns in a blast furnace. Indirectly it has a strong influence on gas utilization performance also termed as η_{CO}. Burden distribution systems in a blast furnace are designed to charge the burden to get the desired layer profile. Profile meters serve as a feedback mechanism for blast furnace operators to ensure desired layer profile is achieved. Conventionally mechanical profile meters are used to measure the top burden surface. The mechanical profilometer involves traversing the probe inside towards the center of the furnace to measure the top burden profile. Which demands holding of charging system for a significant time to avoid any damage of sensors mounted on the probe. It is also associated with heavy lubrication and sealing system for its smooth operation and to avoid leakage of Blast Furnace gas. Considering these shortcomings, a laser-based profile meter system is demonstrated at H Blast Furnace of Tata Steel. It is a noninvasive burden profile measurement technology with lasers mounted on the wall of the furnace and a high-speed pinhole camera capturing the frames of laser pointing to the top burden surface. A smart image processing unit is developed by Tata Steel Research and Development division to recognize the top burden surface and generate a layer profile using scans from multiple charges in a batch. This system is assisting blast furnace operations to monitor the actual layer profile 24 x 7. Due to the simplicity of measurement mechanisms used in this system minimal maintenance is required.

A Method for Predictive Maintenance System for BLT Health Monitoring in Blast Furnace

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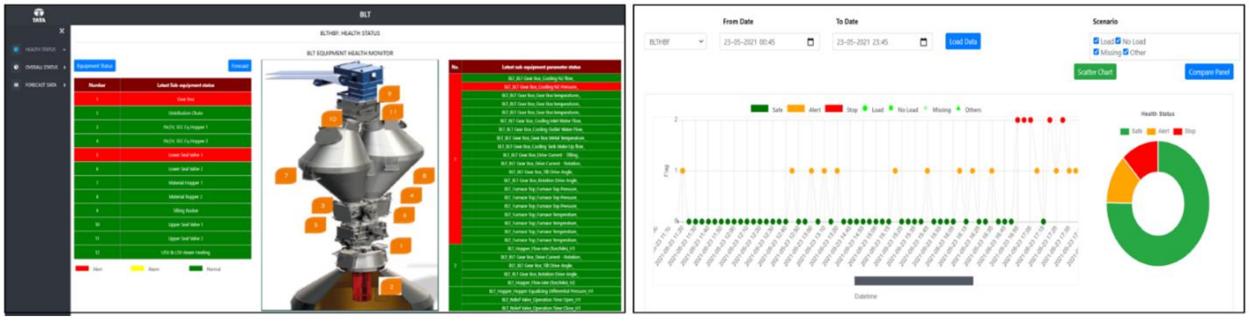
BLT otherwise Bell-less Top is used for charging raw materials into blast furnace to produce hot metal in the iron making process. With different sub equipment connected along with the height of the BLT a series of sequential procedures supports the operation of the BLT. The process of discharging starts right from the top wherein the tilting rocker distributes weights to the two bins of material hoppers to hold the load falling into the furnace. To avoid the weights from falling together at the same time material gates closes and the sealing valve protects the harmful BF gases to escape the furnace top. Hydraulic cylinders operate to open these sealing flaps and by gravity, the load is dispatched to the lowermost of the BLT i.e distribution chute being held by a gearbox which is N2 cooled. The chute rotates and makes an angle to uniformly distribute batches of coke and metallics into the furnace. Each of the activities conducted by individual equipment is important and contributes to a healthy condition of BLT. Unplanned outages impact the targeted hot metal production thus incurring losses. A method to keep a strict eye on the deteriorating health of the BLT is the motivation for a health monitoring system that would act as an early warning system to detect BLT's abnormal behavior. The BLT health monitoring system developed is an integrated machine learning-based analytical solution, carefully tracking the impact of all the operational parameters affecting its operation. This enables us to have an improved diagnostic method to identify faulty components of BLT and identifying the reasons for the anomalies that have impacted the overall equipment. The solution has shown savings of 7 Cr of HM assuming 1 hr of plant stoppage.



Keywords: Iron Making, Blast Furnace, BLT, Machine Learning, Equipment Reliability, AI

Go Beyond Benchmark Yield at New Bar Mill by Online Data Visualization and Prescriptive Analysis

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New Bar Mill (NBM) is a high-speed rolling mill for rebar at Jamshedpur location of Tata Steel. It produces 10 mm, 12 mm, and 16 mm rebar sections with a length of 12 m. Total volume produced in FY'20 is ~ 1.046 million ton. The volume percent of 10 mm, 12 mm and 16 mm is in the range of 33% each. The billets are heated in the reheating furnace above the austenitizing temperatures and rolled in several stands to get the desired cross section. At each stand, the cross section is reduced. NBM consists of roughing, intermediate and finishing stands (No-twist mill). After the intermediate stands, the bar is split into two with the help of power slitter to increase the productivity. The bars are quenched in the water boxes to get the desired mechanical properties and cut to 72-m length bar in the divide shear for cooling in the cooling bed. Yield loss in rolling of rebars is inevitable. The yield depends on the various losses such as scale loss, crop loss, cobble loss, optimization and trimming loss. For a conventional rolling mill, where the billet is heated from the ambient temperature to more than 1200 °C inside reheating furnace, the scale loss is unavoidable. During rolling, the head and tail end of the portion is removed by shear process as they are malformed. After the product is made, the product is trimmed to the saleable length which would also lead to loss. A shear operation is performed finally to cut the rebar to its saleable length of 12 m. Any length of rebar which is below 12 m is bifurcated into two classes: length between 7 m and less than 12 m is marked as short bar and the length below 7 m is scrap.

By leveraging another transformative project taken up in FY'19 to improve yield by ~1% and bring it to benchmark level, TSL was already operating at near benchmark level of yield in its category of product. This time we wanted to exceed the benchmark by further leveraging various technological solutions available to cut on yield losses at most granular level (billets charged) that were still human dependent. With a proper end to end tracking available on a convenient BI platform like Tableau, in terms of losses at any time of the day in all product category, it led to proper control mechanism at shop floor and improved productivity. Operators were even more mindful of plant productivity. This also led to lesser variability across product basket which in turn reduced scrap generation along with improved yield level, thereby helping to achieve lesser CO_2 generation and contributing in organizational goal to achieve sustainable growth. Apart from helping TSL to achieve its objective in all aspects, it will also inspire other similar mills across TSL and outside to aspire higher by technological intervention.
With the implementation of idea, the NBM has been able to achieve and sustain a yield level of more than 97.5% consistently across product offering.

Keywords: NBM (New Bar Mill), TSL- Tata Steel Ltd, BI- Business Intelligence

Optimizing Iron Ore Pelletizing Process using Digital Twin

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In recent times iron ore pelletizing process has gained importance as an agglomeration technology for utilizing low-grade iron ore fines. At Tata Steel ltd Jamshedpur, iron ore pellets constitute around 35-40% of the metallic burden in Blast furnaces. The requirements of pellets for the Blast furnaces are fulfilled by its own 6 MTPA iron ore pellet plant situated at inside the company premises. Therefore, it is of utmost important to produce pellets with good quality at a desired production rate for smooth functioning of the Blast furnaces. While it is possible to operate a pellet, plant based on a common theoretical understanding, a high efficiency operation of pellet plant would require insights which is very specific to a particular pellet plant. So, a complete end to end solution was developed for this 6 MTPA pellet plant in the form of a digital twin based on the data analysis. This digital twin was a complete replica of the existing plant that provided new insights and allowed better process control of the iron ore pellet plant. Present study focuses on the optimization of process parameters that was enabled using the digital twin model.

Digital Model-based Improvement in Steel Melt Shop Productivity

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Manual and semi-automatic operations in steel melt shop provide opportunities to optimize operations. Convertor/EAF, secondary steelmaking, casters and other processing stations need to be in complete coordination to tap maximum productivity and process efficiency. Since ladle transfer is enabled by transfer cars and cranes, tracking of their position and movement is key to coordinating operation. Without this, high variation in operational and waiting time reduces productivity and poses challenge for operators at secondary metallurgy to estimate accurate lift temperature for desired superheat. Temperature of molten metal in tundish, or 'superheat', being in the right range is critical towards ensuring optimum casting speed and high cast quality. Deviation of actual superheat towards the lower end of the desired range causes clogging and even early solidification, whereas deviation towards the higher end leads to lower casting speed.

A comprehensive digital solution has been developed for tracking all cranes, transfer cars and ladles in real time as well as operational duration for heat at processing stations. This enables coordinated operation and movement across the melt shop. The solution's thermal module uses this information to predict lift temperature to enable desired superheat. This thermal module combines a model capturing heat transfer phenomena across various process components with process heuristics to predict the "lift temperature" at ladle furnace and enable desired superheat range at tundish. The model has been tuned and extensively validated against plant measurements for various slab and billet casting grades.

Keywords: Superheat, Digital solution, Lift Temperature, Thermal Module, Steel Melting Shop

Development and Deployment of Phosphorous Prediction Model in LD Converter at SMS

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In BOF steel making, tapping decision is based on the final composition, specifically the phosphorous content. The final composition is ensured through sampling after the blow finish. Accurate prediction of phosphorous through a mathematical model, at the end of blow avoids the waiting time for tapping. In BOF steelmaking, Phosphorous prediction has always been challenging task due to the dynamic interaction between the molten slag and molten steel. The phosphorous distribution at the end of blow between the slag and metal is based on the thermodynamic conditions prevailing at high temperatures, in addition to the mixing and mass transfer variables. In the present study, a novel prediction method for the prediction of phosphorous at the end of BOF process is developed through machine learning by using R software. Experimental data from 200 trials of BOF operation was used for the model with a Random Forest package of R for the development of the model. This model is deployed in an online system, with the help of 3D experience platform. Phosphorous prediction model predicts the phosphorous levels at the end of every heat. The phosphorous prediction model was implemented in the plant and the model shows an accuracy more than 90% for phosphorous prediction at the end of the oxygen blowing in BOF process. The prediction model gets automatically updated with emerging new data and is revised every week at predetermined time.

Keywords: BOF, Phosphorous, R and Random Forest

Implementing Advanced Analytical Tools in Reducing the Carbon Rates at G Blast Furnace, Tata Steel Jamshedpur

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In the era of finished steel supply surpassing the demand and reduction in coking coal availability, integrated steel plants from around the world are switching towards recycling of steel thereby posing a challenge to the sustenance of Blast Furnace Iron making process. The major factor that reduces the operational cost of blast furnace is the segments of fuel, i.e. coke and coal rate, of the blast furnace. Coke comprises about 60% of the hot metal production cost, which accounts for 70% of steel production. Therefore, it is utmost necessary to reduce the coke rates to achieve the low-cost steel production. The reduction in coke rate is possible by debottlenecking the constraints in process flow which could be achieved by predicting the thermal losses ahead. This study describes the proactive measures in the operation of 'G' Blast Furnace, for the reduction of coke rate (coke consumption per ton of hot metal produced) from 340 to 335 kg/thm by process improvements using advanced statistical tools and big data analytical model with 93% accuracy, thereby making a recurring saving of approx. 16 Cr. p.a. INR.

Keywords: Coke Rate, Coking Coal, Heat loss, big data Analytics

Blast Furnace Health Management: Next Level Monitoring with Digital Interventions at H Blast Furnace, Tata Steel Jamshedpur

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With the improvement in process technology and automation of processes, the productivity of the blast furnaces has increased considerably. This has resulted in the need for close monitoring the health of all blast furnace equipment. The availability of all the sub processes and equipment needs to be 100% since any outage can potentially cause a huge loss of production. The thousands of instruments used in blast furnaces are typically monitored from the control room. Despite having different levels of monitoring and alarm systems, it may happen that the operator keeps monitoring instrument of lower criticality while the health of a very important instrument may have gradually become very critical. This may have been averted if the operator had paid attention to the right instrument at the right time. In the present study, an instrument health status and health prediction model based on machine learning and artificial intelligence is being considered. All the major areas of the blast furnace were included in the scope of this model including burden distribution, blast furnace proper, GCP, cooling circuits and cast house. The variables in these major areas which determine the KPIs governing the health of the furnace were identified and machine learning models were built using the historical data for these variables. By predicting the values of these KPIs, the models can forecast potential failures and malfunctions. Real time alerts can be raised upon the identification of unhealthy state of the equipment. The study shows that the blast furnace health models have enabled operators and maintenance personnel to take proactive measures for avoiding unstable conditions and stoppages.

Keywords: blast furnace processes monitoring, machine learning, equipment criticality, forecasting failures, real time alerts, proactive measures

Simulation Approach Developed to Optimize the Cost at LDC using Forecasted Load and Frequency ML Models

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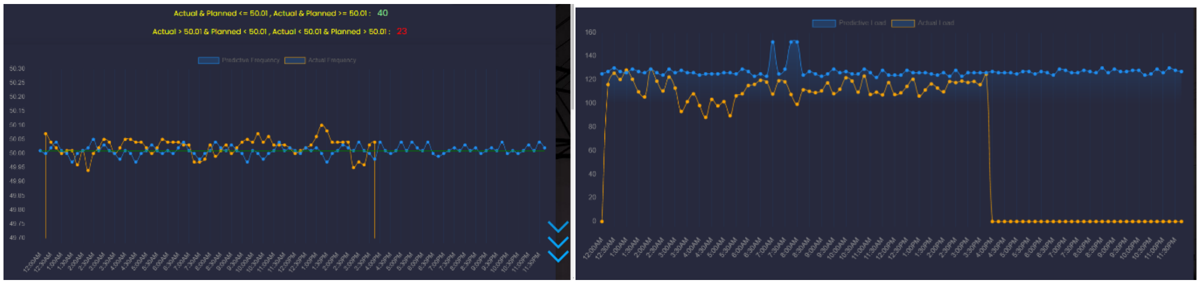
Power Grid Corporation has given open access to transmission or distribution of power and associated facilities to any licensee or any consumer. In open access, Power is scheduled every 15 minutes block of a day, one day prior the actual usage. Any kind of deviation from the schedule is settled as per deviation settlement mechanism (DSM). For instance, if frequency is low and power is drawn above the given limit, penalty will be imposed. Similarly, if frequency is high, drawl is also more, then it is a benefit. But the data-driven machine learning models are not giving very accurate results. To accurate the predictions, a simulation approach has been adopte d on top of ml-based forecasted values. To give an optimum schedule, following steps are followed: from historical data, calculate the deviation of (a) Predicted Load from Actual Load (Delta Load) and (b) Predicted Frequency from Actual Frequency (Delta Frequency). Take the Probability distribution of the above deviations (Error distribution) and perform a Kolmogorv Smirnov Test and check for the matching. After that from the parameters of the matching distribution, 1000 random samples of delta load and delta frequency are drawn.
Perform a simulation in the following way:

- Take the 1000 random samples of delta load and 1000 random samples of delta frequency and iterate through them.
- Add the delta load to Predicted load. -> new_predicted_load
- Add the delta frequency to Predicted Frequency. -> new_predicted_frequency
- If the sampled delta load is greater or lesser than 12% of the Predicted Load values, exclude that sample.
- Calculate the new cost based on the variables
  - new_predicted_load and new_predicted_frequency based on the following formula:
- New Cost = DVC_Cost * new_predicted_load + UI_Cost (For new_predicted_frequency) * delta_load.
- Take the sample which is giving the minimum cost through all the iterations. Suggest that sample as the optimum schedule.

Keywords: Load Forecast; data-driven models, simulation approach, error distribution



Achieving Excellence in Operation with Artificial Intelligence – Burden Recommender Model

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H Blast Furnace is one of the largest blast furnaces in the world (volume = 9230 m^3 and average daily production = 9200 TPD). The distribution of burden inside the blast furnace is a key enabler in ensuring high productivity and long campaign life of the blast furnace. All bell-less top charging systems have a burden distribution matrix designed by operators which is used to achieve a uniform distribution of burden in the blast furnace. At present, the system is reactive with respect to the changing raw material properties and operating parameters. The operators constantly monitor the furnace condition and tweak the distribution based on their experience to keep the furnace performance stable. However, there is no tool available at present to forecast the effect of these changes and recommend burden distribution based on the forecasted values. The present study considers a predictive model which uses machine learning techniques to analyse raw material size, raw material moisture levels, burden profile generated by laser profilometer and 300 other process parameters for generating a burden distribution matrix with the aim of improving the current values of furnace performance indicators.

Keywords: Burden distribution, bell-less top charging, predictive model, machine learning

Blast Furnace Process Improvements through Digital Initiative, JSW Steel Limited

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Ironmaking process involves highly complex process technology and equipment. This provides good scope for research and development with supporting environment for the application big data analytics for enhancing the level of ironmaking intelligence. The blast furnace process is a "black box" operation, and the smelting process is unpredictable. During the long-term operation of the blast furnace, a large amount of smelting process data has been accumulated, providing full lever to utilize the value of big data, and deep mining of the inherent laws contained in big data through artificial intelligence technology. Since JSW Blast Furnace are operating with high gangue input, it was necessary to develop the prediction model. This paper describes the development of cohesive zone prediction model and Hot Metal silicon prediction model. Both models helped in optimize the fuel rate of large blast furnace to 520 kg/thm.

Keywords: Large blast furnace, low fuel rate, lower cost, higher PCI rate

Safety

KEYNOTE LECTURES

Digitalization of Process Safety Performance Indicators (PSPI) for Better Business Results

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'Excellence in Process Safety Management' has been identified as one of the key safety strategies at Tata Steel for achieving the objective of 'Committed to Zero'. Tata Steel adopted Process Safety Management (PSM) in its present form in the year 2006. A firm foundation has been laid across TSL through a structured approach of "Centre of Excellence (COE)" concept. It was piloted in two manufacturing units in the year 2017 and have been extended gradually to 46 high hazard departments by 2020.
Measuring performance is imperative to any management system and forms the basis for standardization and continuous improvement. Effectiveness of PSM depends on management and review of key process safety performance indicators (PSPIs). Accordingly, PSPIs including both lead and lag indicators were identified which started being reviewed using an excel based dashboard. The data used to be sourced from various locations namely logbooks, level-1&2 systems, SAP PM, Safety Management system-Ensafe, etc. Collecting data used to be cumbersome involving erroneous entries at times. To address this issue, a digital platform replicating the existing dashboard has been developed. It fetches data automatically from multiple locations and provides customized displays to users. It facilitates real time monitoring of PSPIs by users and escalates deviations to central safety team and senior leadership. During the deployment, many data points, especially in old units got upgraded and automated using sensors and probes. Digitalization of PSPI has been a key intervention to strengthen the PSM deployment further. It brought transparency in reporting of PSM related deviations, standardized the reporting process and promoted multi-level monitoring through remote access and real-time alerts. FY19-20 saw about 65 % reduction in red category incidents attributed to failure of PSM critical equipment and parameters.

Developments in Occupational Health and Safety Management Systems & Practical Ways for Accident Prevention in Metallurgical Industry Sector

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VISION ZERO is becoming more widely known and being pursued around the world. The heads of government of the seven most advanced industrial nations, known as the G7, also announced their commitment to VISION ZERO and their global responsibility at their annual meeting in 2015 in Elmau, Germany.

Metallurgical industry is characterized as dangerous owing to its highly hazardous activities. The traditional approach has been on ensuring compliance. This approach is reactive with limited results.

The modern approach has shifted away from traditional regulatory compliance based reactive approach to a combination of proactive approaches. Organizations have realized the role of robust safety management systems (SMS) and thus developing their own SMS framework and goal zero policies. This strategic shift in the last few decades has paid clear dividends across the industry sector. For instance, world steel industry reported a steady and notable reduction in the combined LTFR per million hours worked from 4.55 in 2006 to 0.83 in 2019, a reduction of 82%.

Safety management systems are used to systematically manage safety risks. It integrates active safety management tools, including senior management commitment, hazard identification, risk management, risk mitigation, safety reporting, audit, investigations and remedial actions, safety culture and education supported by clear policies and processes. Over the last few decades there has been a proliferation of formal safety management systems such as HSE, UK(HSG65); The European Framework Directive on Safety and Health at Work (Directive 89/391 EEC); ANSI/ASSP Z10.0-2019; ISO 45001; PSM (OSHA CFR 1910.119); CCPS – RBPSM; HSE UK COMAH Regulations.

The presentation intends to describe the overview, structure and principles used in these safety management approaches ranging from reactive, proactive, and predictive aspects. The aim is to show how organization specific fit-for-purpose safety management systems can be developed considering these SMS frameworks. In addition, the talk shall focus on some high impact practical ways to practice goal zero vision based on technical research of high reliability organizations.

Breakthrough Innovation in Safety

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In the last two decades, the world has seen important technological developments such as Industry 4.0 that has changed the production/work systems, processes and monitoring, control and communication methodologies/protocols. Keeping with the pace of these developments, several breakthroughs have taken place or been proposed in the domain of safety science, engineering and management (SSEM). The key developments include (i) safety analytics, (ii) use of exponential technologies for collaborative learning, (iii) innovative design, and (iv) safety economics. In this article, the author elaborates the concepts, principles and applications of these developments for enhanced safety management.

Keywords: Safety management, safety analytics, exponential technologies, collaborative learning, safety economics.

Safety Competency Development of Workforce to Achieve Zero Harm at Tata Steel

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Health and Safety Management is Tata Steel's foremost priority. In pursuit of achieving long term objective of 'Zero Harm', the Company continues to work on the identified six safety strategies. Over the past 16 years of safety excellence journey, several interventions have been taken and company has achieved a lower than industry average in lag indicators. Still it is at quite some distance from achieving 'Zero Harm'.
The company believes that safety competency development of workforce in hazard identification to improve risk perception is key to achieve the long-term objective of 'Zero harm'. Analysis of incidents points towards non-uniform understanding of workforce on safety standards. To build safety competency, several steps have been taken. The company has taken initiative to simplify all the safety standards and convert the same into two types of learning modules in vernacular languages, namely practitioner and master. All the employees based on the position codes have been mapped with relevant E-learning modules, which are assigned and tracked periodically for compliances. To educate about disruptions made, in the traditional way of safety induction

training, Safety Leadership Development Centre (SLDC) was conceptualized and implemented. Now the training module at SLDC has been made a compulsory condition for working. Taking a step forward, Practical Training Centre has been conceptualized to provide hazard specific training via practical approach and leveraging technologies such as AR/VR. Successful completion of the modules will allow people to work in those identified hazardous area.
All the above-mentioned initiatives will be a game changer in improving risk perception of the workforce and will surely help to achieve stated objective of zero harm.

Keywords*:* Zero harm, Safety Strategies, Safety Standards, Safety Leadership Development Centre, Risk perception.

Risk Based Process Safety Management

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The paper will expose participants with the Risk Based Process Safety Management System.
The elements of the Risk Based Process Safety Management systems will be explained in detail which will help participants in designing, developing and installing such a system.
The objective of the presentation is to equip the participants to find effective ways to improve their existing process safety management system to become more effective and operate process safely based on Risk Based Process Safety Management.
The scope of the presentation is to introduce in a simplified manner the work breakdown structure of all the twenty elements, comprising of four pillars of Risk Based Process Safety Management system starting with description of the element, the key principles, essential features, work activity and implementation options.
It will deal with all accepts of Process Safety management and need for Risk Based Process Safety.
Relevance of PSM in hazardous industries in general and steel industry in particular will be discussed. The road map for implementation and governance of Risk Based Process Safety Management will be shown. The presentation will include discussions on industrial accidents along with root causes. The lecture will highlight various regulations, standards and guidelines on Process Safety Management.
The lecture will deal with key operational risks in the production process in the steel industry. It will also highlight the recurring gaps in the Process Safety Risk Management across various industries. The importance of operational discipline to achieve operational excellence and the consequence of not adhering to it will be touched upon. The presentation will include three-dimensional nature of safety and different drivers of process safety. The leadership role and commitment is core to process safety. The need to shift focus from Safety to Risk Management is

of primary importance if we want an incident free operation.

Connected Worker

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Connected worker ecosystem improves work safety, provides intelligence insights, and offers enhanced decision support through the use of intelligent sensors, safety PPEs and wearables. Connected worker ecosystem offers functionalities such as work assignments, work execution, performance analysis, and safety monitoring.

Our connected workforce solutions consists of Employee Health and Safety wearable and SafePass – Smart ID card, which enhances worker well-being, minimizes workplace risks and boosts productivity in industrial or campus setup.

Employee Health and Safety Wearable: The EHS wearable is an industrial and workplace safety system. It has features like

- Heart rate and skin temperature measurement.
- Fall and immobility sensing, SOS.
- Hazardous area alerts.

It gives real-time visibility into the health and safety of worker with the ability to react instantly to an anomaly or an incident.

Benefits of the solution are:

- Vitals monitoring helps by alerting threshold breaches hence saving looming accidents.
- Ensuring quick turnaround of medical assistance.
- SOS alert is effective for saving individual life and can be used for alarming any mishaps.
- Derive job fitment, fatigue management, employee productivity, reduction in injury loss time and insurance costs.

SafePass – Smart ID Card: Tata communications SafePass is a workplace worker tracking / monitoring system. It has features like

- Safety – SOS.
- Tracking, hazardous area alerts.

It provides the company near real-time visibility into where the workers are in the plant. It enables workers to alert safety teams via the SOS button and it alerts the workers while entering a hazardous area.

Benefits of the solution are:

- Tracking to ensure productivity.
- Contractor cost management.
- SOS alert is effective for saving individual life and can be used for alarming any mishaps.

Transformative Technologies and Business Solutions for Safety Management Issues and Challenges

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Technology, just like a living organism, develops, stagnates and declines. No technology remains fixed. Today technology is changing too fast and in so many directions making us the victims of the next new thing fatigue but at the same time providing us with new solutions to our age-old engineering problems and associated challenges. Furthermore, these technologies are also providing us with new tools and methodologies facilitating implementation of transformative business solutions to ensure planned performance of the engineering assets in a safe and cost-effective way.

Technologies such as big data analytics (predictive and prescriptive analytics), IIoT, ML, communication technologies, etc. that offer near perfect solutions for managing engineering assets are collectively termed as transformative technologies. Such technologies facilitate or are expected to facilitate correct decisions by using the power of predictive and prescriptive analytics by the designers or assets managers to ensure expected performance in terms of cost, capacity, productivity and safety, etc. Such technologies ensure the use of new or ageing engineering assets with almost no risks.

However, implementation of transformative technologies also requires an equal focus on human and organizational culture to address the stakeholder's requirements regarding safety and cost competitiveness. The accelerated development and deployment of new technologies not only brings shifts in industrial management paradigm but also affects the work and organizational culture of the organization. Many times, this leads to new types of safety challenges impacting safety at work places apart from social and cultural conflicts.

The presentation will highlight the issues, challenges, and future directions for implementing transformative technologies to address the stakeholder's requirements on production capacity, productivity and safety in different industrial sectors based on experiences from Swedish industry and research initiatives with examples from railway, aviation, mining, manufacturing, energy, etc. sectors.

Keywords: Transformative technologies, Predictive and prescriptive technologies, Safety management, Human factors, Organizational culture

Key Performance Indicators for the Assessment of Inherent Safety and Escalation Hazard in the Early Process Design

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Industrial processes where hazardous chemical substances are used may cause significant hazards related to fires, explosions and toxic dispersions. Key performance indicators (KPIs) may play a relevant role in the identification, control and management of such hazards and of the related risks. The use of specific KPIs since the early design of processes may lead to the selection of safety-effective design solutions. In particular, during the early stage of process design, a simplified and straightforward approach to the quantitative assessment of inherent safety and escalation hazard may be a suitable tool to provide guidelines for proper design choices. Nevertheless, existing methods for inherent safety assessment are mainly aimed at the general assessment of chemical reaction processes, not focusing on escalation hazard. Recently, specific approaches were developed for the comparison of expected safety performances among different process alternatives, focusing on escalation hazard analysis. The KPIs made available allow the quantification of inherent hazards, also addressing escalation hazard, allowing the identification of the inherently safer process alternative. Critical elements and safety distances necessary to prevent escalation effects are also provided by the KPI calculation. A test case will be illustrated to demonstrate the use of inherent safety KPIs in the selection among alternatives.

Science of Fit

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When it comes to choosing the right PPE (personal protective equipment) to help protect individuals from occupational hazards while at work, the most important thing to consider is the type of hazard they will be exposed to. Once you have determined this, the two major factors that

should come into consideration while choosing a right PPE are i) comfort and ii) fit.
A pair of safety glasses that feels comfortable on one person might not feel comfortable on another. One of the main reasons for this is the head size and face shape. The facial structure of men and women across different ethnicities can vary greatly and the size of cheekbones, nose bridges and ears can also affect the fit of eyewear.
When choosing a respirator for the job at hand, it is important to choose one that fits properly to ensure workers are protected from the hazards they are exposed to. Tight-fitting respirators must seal to the worker's face to provide expected protection. The reason why proper respirator fit is so important is because it involves three major components of which all must be accommodated for to get the required protection: Seal, Compatibility and Stability. Air will take the path of least resistance, so if a respirator is not properly sealed around the wearer's skin, the air will enter the respirator at the break in the seal rather than through the respirator – lessening the protection and potentially leading to hazardous exposure.
Another factor that should be considered is the compatibility with other types of required personal protective equipment (PPE) and ensuring that they all fit comfortably together. This is one of the reasons that eyewear can be among the hardest parts of PPE to fit properly. Over the years, 3M has been applying the science of Fit while designing PPEs for users.This keynote will highlight the importance of Fit and the science behind it.

ORAL PRESENTATIONS

Risk based Inspection

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Process Safety Management is an analytical tool focused on preventing releases of any substance defined as a 'highly hazardous chemical'. Any such release may be due to failure of safety critical task or failure of safety critical equipment. Risk based inspection is a part of one of the elements of process safety management that is mechanical integrity and quality assurance.
The Risk Based Inspection (RBI) approach is focused on maintaining the mechanical integrity of all static assets which if allowed to deteriorate would potentially lead to loss of containment, e.g. tanks, gas mains, process pipes, etc. RBI also focuses on understanding failure modes, addressing the modes and therefore improving the reliability of equipment and process plant.
Risk based inspection involves planning of an inspection as per the information obtained from a risk analysis of the equipment. The risk assessment gives risk category for an individual asset and is used in conjunction with a questionnaire to determine the inspection strategy.
Risk based inspection process flow should be as follows:
Define system boundaries of the Asset

- Develop asset inventory
- Define degrading mechanism
- Carry out risk assessment
- Develop an inspection strategy
- Implement inspection strategy
- Review inspection results
- Update integrity management system

If we are going to implement the risk based inspection, risk assessment and development of inspection strategy are of the utmost importance. Risk assessment includes identifying failure scenarios, determination of susceptibility to each failure mechanism, determination of consequence of failure, overall risk category, etc. Developing an inspection strategy method should include initial detailed inspection, follow-up inspection interval based on known or projected degradation rates, determine the type of inspection e.g. general visual, ultrasonic spot thickness measurement, corrosion mapping, magnetic particle inspection, ultrasonic crack detection, etc., develop inspection instructions and include the same in the maintenance management system for integration and overall risk reduction.

Deployment of Past Incidents Learnings to Avoid Recurrence

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An integrated steel plant is full of hazards at every value chain of its operation. Learning from past incidents is a useful approach when examining past events and developing measures to prevent ensuing recurrence. The focus is on making sure that the lessons learned from incident investigations are implemented and lead to an actual improvement in safety.
In TSL, many incidents have happened which are repetitive in nature and it is difficult for TSL to deploy the learnings uniformly across the organization. When incidents occur, they raise awareness and understanding of things that went wrong but it is often limited to that department/section. To ensure deployment across the organization, an exercise was conducted to identify the key recommendations from the recommendations received through fatal incidents that happened in past 15 years. The IT based system is mapped to ensure coverage at each area implementation committee (AIC). The key recommendations are assigned to the line managers with concurrence of AIC Chairman and they ensure the deployment and update the compliance in the IT System, after which the safety professionals of that AIC verify the deployment and in case of unsatisfactory deployment, they are authorized to return for re-deployment.
Through this IT based system, past experiences of previous incidents are translated into preventive measures, using which as an organization, we can prevent incidents in the future and the need for repressive actions at time.

Keywords: Learning from the incidents, recurrence of Incidents, Area implementation committee, incident investigation

Driving Road Safety through Technology and Artificial Intelligence

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Background: Once designed to produce 1 MTPA, Tata Steel Jamshedpur plant today produces 10 MTPA steel at the same site. Production and outbound despatch of 10 MTPA steel also require inward movement of 30 MT raw material. This movement at the plant is supported by a logistics infrastructure comprising 93 km of roads and 223 km of rail. The plant has a complex mix of traffic, comprising people, heavy vehicles, two-wheelers and four-wheelers. This complexity poses many road safety related challenges. Over the years, innumerable infrastructural improvement initiatives were undertaken to eliminate road related incidents/injuries. While these initiatives helped reduce the number of incidents/injuries, a considerable gap remained in achieving the target of zero road incidents.

Brief Description: Analysis of past data detected that 80 % of road incidents occurred due to unsafe behavior with two key causes: over speeding and driver fatigue.

Handheld speed cameras and CCTV camera installation made the road incidents trend fall but incidents still continued to occur because of inherent limitations:

- Manual processes can be undertaken for limited time
- The feed from a large number of cameras not getting viewed 24x7
- Violations not getting rectified on real time basis

How is it applied: The AI based software enables highly refined video content analytics, covering the entire content of video, creating a structured database of information from unstructured video feed. Introduction of AI technology helped address earlier issues, but also posed a new challenge - identification of road violators on a 24x7 basis with the challenge becoming acute at night. To address this, an Automated Number Plate Recognition (ANPR) technology for real time identification of violators was implemented to accurately read vehicle license plates from multiple lanes in any light condition.

This has helped reduce unintentional over speeding by 70 %.

A Systematic Approach of Improving Workplace Safety – through "Hardware Intervention Projects driven by Safety Departments"

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Background: In the current context, across TSBSL, we have identified several high hazard risks mainly due to the manual nature of the job, design issues, and cultural related issues. In the last 3 years, we have taken several improvement initiatives/projects at Khopoli to eliminate man-machine interface hazards, though there are several areas where inbuilt design, space, and storage constraints remain.

Problems: Though there is a substantial increase in number of injury cases, we are still witnessing 6-8 serious injury cases (LTI) in a year. One of the common points which came out from most of the incidents' root cause analysis is the lack of "man-machine interface". We have in-built machine design constraints from OEM in some of the process lines like NCRM H&T, polishing machine and WCRM rewinding lines. Most of the CRS and CTL lines in NCRM are designed and commissioned by an internal team with only productivity in mind. This resulted in very little storage space for RM and FG and multiple manual activities had to be done where the worker was directly exposed to the running sheet. In tubes, operator has to feed tube manually to all draw benches and tube cutting machines which is the main reason for injuries that happens in tubes.

Contributions: With detailed incident investigations, we have identified "Hardware interface projects". First, we listed down all fatal potential unsafe conditions like no barricading on crane gantry, no narrow coil storage stands, no gas leak detection system in ammonia storage tanks, etc. In addition to this, with the help of the past 15 years of fatal recommendations, learnings from incidents that happened in TSL, and recommendations from government 3rd Party audits, we have also listed down common recommendations, which we identified as projects and similarly completion as per standard and on the fast route. Then, we listed down all high-risk activities and marked their SOP as Red SOP. We identified projects to reduce risks in high-risk activities and ultimately converted Red SOP into Green SOP. We have many legal non-compliances, for example, gas leak detection systems, fire safety in cellars, etc. which are also taken as hardware projects and completion is under progress. These "Hardware Intervention projects" initiatives have brought in several improvements to the shop floor.

Implications: The deployment of this initiative has led to the elimination of fatal potential unsafe conditions, reduction in the severity of high risks activity, and legal compliances. This has led to several improvements at the shop floor level with Kaizens with horizontal deployment. Most important it has increased morale of shop floor workers with the involvement of top leadership in the safety improvement journey.

Auto Tracking & Control of Human Intrusion at Bundling Stations

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In New Bar Mill (NBM), Tata Steel, billet (of cross-section 150x150 mm^2) is rolled into rebars of three cross sections namely 10, 12 and 16 mm. The final thermomechanical treated rebar comes to cooling bed to complete the tempering process in normal ambient temperature. After length optimization, bars fall on cooling bed at multiples of 12 m length (maximum: 72 m, minimum: 24 m), but due to process constraints all different length bars cannot be dropped on cooling bed at the same location. Through aligning roller, the entire bar head is aligned at the end of the bed before it reaches to roller table for final sizing of customer length 12 m. If bar head is not aligned while final sizing, there will be generation of lots of non-prime, short re-bars (re-bars less than 12 m in length). To prevent the chances of short re-bars from going in prime bundle (bundle of 12 m length), sorting of short bars are done manually (24x7x 365days) by hand from the layers in bundling station area. Layers in bundling station area are continuously moving so safety emergency control stop button must be operated to stop the layer before sorting. But there was an incident when a person went for sorting without operating safety emergency and got hurt by hitting with the layer.
In our current innovation, sensor-based intelligent tracking of human intrusion in bundling area is developed to fool-proof the area by stopping the layers movement on bundling station even if safety switch is not operated. This fool proofing is achieved with the help of simple gadget i.e. Sick Make Diffused PED which was commonly used for material tracking but was thought for the first time that it can also be used as an important safety barrier which can prevent the human intrusion in such a hazard prone area. The idea was quite innovative since no one thought that this simple cost- effective sensor can be used for detecting human presence. There are lot of standard solutions available in the market but from a rolling mill point of view these sensors are either very costly or not suitable for a steel industry environment or they are highly maintenance prone and may result into unwanted outages due to malfunctioning.
This innovation has helped us eliminate a safety hazard whose mitigation plan was earlier based on administrative control only but now an active barrier has been deployed which has provided fool-proof solution. Thus, both quality of products reaching the final customer as well as safety are ensured at the same time.

Keywords: Human intrusion, sensor, PED, rebar, Tata Steel.

Automation of Raw Material Handling System (RMHS) Day Bin Material Bunker Feeding System for MBF1 & 2

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Mini blast furnace (MBF) produces molten metal (Fe) using different raw materials like iron ore, sinter, fluxes and coke in a predefined ratio. The molten metal is directly used by our DI pipe plant for pipe manufacturing whereas pig iron is used by external foundries.

The RMHS is an integral part of the MBF. Here raw materials are weighed and fed to the MBF. But earlier the material feeding system to the day bin bunkers of RMHS from where the materials were weighed in the weigh bins was a totally manual operation. This had many hazards indicating serious concern for the people as well as process safety like

- Dusty environment caused by material transfer.
- Material mixing in Day Bins.
- Chute change-over from the transfer trolley (risky activity)
- Inspection of the day bin bunker level (risky activity)
- Material spillage

To mitigate this, we developed an in-house automated system which removed all hazardous activities. The operator can view and control the process ground hopper control room, hence there is no need to operate the system from the bunker top.

This also provide some additional benefits like

- Online data availability to MBF control room about the day bin level.
- Data acquisition and trend facility.
- Elimination of the chance of the material mixing through logical interlocks.
- Remote area monitoring through CCTV with recording facility to find out the gaps.
- Morally boosted operator (Happy and productive manpower).

So, in a nut shell, this automation resulted in reduction of operator fatigue, engagement through elimination of man-machine interference and thereby improving operational safety. Furthermore, it also resulted in manpower reduction (~17,500+ man hours per year). Consequently, there was improvement of manpower productivity via optimization of manpower.

New Technology based Safety Management in Road & Rail Safety at Tata Steel

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At Tata Steel road management and rail movement is a challenge due to high traffic load and behavioral based unsafe act. The fatality rate was too high on road due to poor infrastructure. We are continuously dealing with challenges like drowsiness, over speeding, derailment, side collision, dashing and toppling of vehicles.
Digitization can help to solve these issues. At Tata Steel, we are working on road and rail safety improvements. Digitalization not only help to control things easily but also reduces manual intervention. Implementing digital solutions, rethinking the root cause and solutions to be made by incorporating positive barriers is done. We implemented driver fatigue monitoring in a web based platform where every violation can be detected and zero incidents can be achieved. Implementation of radar display and ANPR helped us to alert road users proactively. Digital intervention using artificial intelligence are being deployed for preventing man-machine interface at forklift operation successfully. Brief cam operation is helping us to create positive reinforcement in behavior of riders on road. Technology like video analytics are helping us to capture violations automatically. Interlock based loco operation will help us to make loco operation safer. No one can rise on or come down from a running loco. As toppling is a great concern at pick and carry crane, our sensor based technology will be helpful. We hope digital platform will help us to achieve zero harm. Automation helps not only to reduce manpower but engage people in other activities. Automation has played a vital role in safety. Now safety related projects are taken more seriously and getting more focus. Continuous improvement is going on in pain areas to eliminate them phase wise. Digitization and AI in safety will help to eliminate unsafe practices at shop floor and achieve zero harm.

Human Reliability Assessment of Critical Manual Task using Human Error Assessment and Reduction Technique (HEART)

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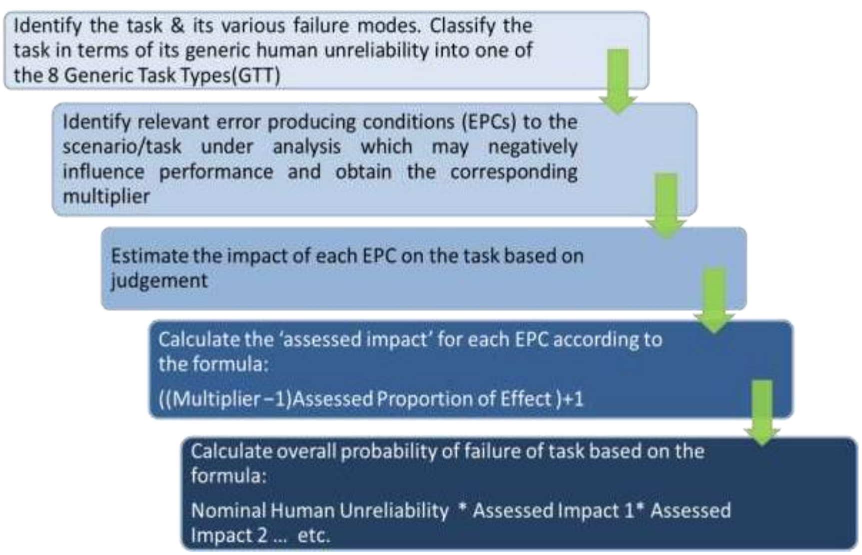
Human Reliability Assessment (HRA) is used to predict how likely it is that a process will fail based on the potential of human error. It includes both qualitative and quantitative methods of assessment. The Human Error Assessment and Reduction Technique (HEART) is a HRA method based on human performance literature which was developed by Williams (1986). HEART assesses the interactions between humans, their specific tasks and performance shaping/human factors or error producing conditions (EPCs). HEART analysis consists of 5 major steps as shown below.



Concern: We were facing several instances of loco derailment in hot metal logistics area. Loco operation is a manual process and most of such instances were due to manual error.

Analysis:

- Past 3 years incident data analysed to find out the critical task in which error contributed to maximum number of derailments.

- Fault tree analysis (FTA) of the critical task was done.
- Human Error probability was calculated for all failure modes as per FTA.

Solution: 18 recommendations were generated either to eliminate the human error or to reduce its error probability. Few major areas of recommendations are:

- Quality of SOP - To reduce the ambiguity
- Instrumentation - Early warning indication
- Skill and competency development
- Improvement of maintenance practices

Conclusion: HEART has given us an insight to look at human errors from a different perspective and helped us to identify solutions for error reduction. 9 recommendations have been implemented till date and it has resulted in a 60% reduction of incidents compared to H1(YTD) of FY21.

Leveraging Digital Technologies to Build Safety Competency of Workforce to Achieve Zero Harm at Tata Steel

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Health and Safety Management is Tata Steel's foremost priority. In the pursuit of achieving long term objective of "Zero Harm", the company continues to work on identified six safety strategies. Over the past 16 years of safety excellence journey, several interventions have been taken and company has achieved lower than industry average in lag indicators. Still it is at quite a distance from achieving zero harm.

One of the six safety strategies at Tata Steel is 'improve competency and capability for hazard identification and risk management'. Over the years, several initiatives have been undertaken to develop competency of workforce but injuries among the contractor workforce remained a concern. The need was felt to adopt innovative approach to build competency of workforce on prioritized safety standards to improve risk perception.

A state of the art 'Safety Leadership Development Centre' was conceptualized and implemented in 2020 to build safety competency of workforce on safety standards. Past 15 years injuries were analysed and mapped against safety standards. Top 11 safety standards were prioritized to build competency of workforce. Training methodology adopted is in the form of guided tour in 12 different zones equipped with physical props, world class audio video (AV), displays, posters, etc. In the AVs, actual accident scenarios, likely consequences of not adhering to safety standards have been simulated and correct rules and procedures have also been explained to sensitize the workforce. The entire guided tour is of a duration of 2.5 hr. Post completion of tour, dissemination

of the knowledge is verified through multilingual interactive test modules. Entire process is automated; booking slots for training, test app and real-time updates of result. This focused innovative learning experience on safety standards and periodical refresher will help to improve risk perception of the workforce.
In FY 20-21, ~14000 persons have been trained and Lost Time Injury of trained workforce is NIL.

Keywords: Zero harm, Safety Strategies, Safety Standards, Safety Leadership Development Centre, Guided Tour, Risk perception.

Learnings from Failures of Safety-critical Boiler Tubes: Metallurgical Insights

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Boiler tubes are an integral component of power houses carrying the pressurized steam at elevated temperatures to eventually convert the thermal energy of steam into electrical energy by rotating the turbine. Failure of boiler tubes often leads to both safety threats as well as loss of productivity. In the present work, a number of case studies of metallurgical failure analysis of boiler tubes is put forward. The implication of different macroscopic features like fish-mouth opening, thinning, scaling, circumferential and longitudinal cracks and microscopic characteristics including the nature of scale and its chemical constituents, in-service phase transformations like spheroidizing of pearlite, formation of bainite and acicular ferrite, role of non-metallic inclusions is discussed in detail. Metallurgical mechanism behind different failure modes of boiler tubes, namely thermal fatigue, creep, short and long-term overheating, dew point corrosion, stress corrosion cracking and sulfidation attack is proposed. Specific recommendations to prevent these failures from both metallurgical and operational standpoints are suggested.

Keywords: Boiler tubes, failure modes, Phase transformations, Dew point corrosion, Creep.

Safety Initiatives for Injury free Major Shutdown in Sinter Making Plant

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Sinter plants agglomerate iron ore fines (dust) with other fine materials at high temperature to create a product that can be used in a blast furnace. The final product, a sinter, is a small, irregular nodule of iron mixed with small amounts of other minerals. The process, called sintering, causes the constituent materials to fuse to make a single porous particle with little change in the chemical properties of the ingredients. The purpose of sinter is to be used in blast furnace to converting iron ore into molten iron.

Major shutdown is defined as a shutdown which takes place for a period beyond 48 hours. Numerous activities are carried out in major shutdowns which are manually intensive and also involve material handling of heavy spares and machinery.

This is regarding a case study of one such shutdown in sinter making unit in a steel industry where due to rigorous and planned audit process, the shutdown could be completed as injury free.

Major jobs like complete refurbishment of ignition furnace, change of both cooler silencers, guillotine damper change (inlet and outlet), waste gas fan motor change, wind box change, etc. were taken up with approx. 550 contract employees and 120 TSL employees engaged per day.

Audits by central safety team, WSEIs, line managers including 10 night audits were carried out. It was seen that the trend of violations with these audits went on decreasing with days. Rise in covid-19 cases was a great threat with increased manpower in shopfloor. Digitalization initiatives were undertaken to track Covid preventive measures.

The violations captured were categorized into 10 categories (unsafe acts / unsafe conditions). The paper aims to capture the vital few categories that need to be focused to have an injury free shutdown.

A Systematic Approach of Improving Contractor Safety Performance – through Business Partner Safety Annual Business Plan

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Background: Iron making division in any steel industry starts from the process of sourcing of raw materials, coke making, sinter making, making of hot metal in blast furnaces and then transportation to steel melting shops. All of these processes are of high risk and involve about 50 % of contract workforce. Most of the improvements at workplace take place in reactive manner.
Problems: Almost 70 % of the injuries in workplace are related to contract workforce. While systems like start rating evaluation (OHSAS), safety audits are in place in the organisation, they still do not help in continuous improvement and hand holding of the business partners. Moreover, given the attrition rate of the contract workforce, skill development is a challenge for the high-risk nature of these jobs. There are many grey areas like road safety, spillages, etc. where contract partners do not contribute.
Contributions: The current method has aligned the business partners to the central safety corporate annual business plan and the central safety initiatives. The safety ABP driven by 16 KPIs which includes involvement of senior management of the business partner, initiatives like small group improvement and job cycle check, health initiatives, etc. have brought in several improvements in the shopfloor.
Implications: The deployment of this initiative has led to the sustenance of star rating score while the assessment criteria have become stringent. It has led to several improvements at shopfloor level through small group activities by vendor groups, job cycle checks by vendor supervisors and subsequent changes in standard operating procedures and also systemic improvements like skill development, involvement of top leadership in safety improvement journey in synchronization with the parent company.

A Safe Practice of Covering Tarpaulin using Safe Platform & Personal Fall Protection System at Tarpaulin Covering Shed at Out Bound Logistics TATA Steel BSL

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Background: On-road finished product despatch is a major logistics activity at TSBSL Angul. On-road despatch is being done for HR and CR coils from HSM and CRM. Daily 100 long trailers are entering the plant for finished product despatch from HSM and CRM.
Problems: After loading on trailers and quality checking, drivers were covering tarpaulin on the finished product on trailers, which meant that after loading there were very small spaces on trailers on both RHS and LHS side for movement. There were two first aid incidents reported which

occurred during loading and lashing by drivers. Drivers were untrained to do this skilled job on a low fall height, the tools and tackles were not standard which were leading to slip, trip fall. Drivers used to go on top of the truck to take the tarpaulin from their storage place which had serious injury potential of fall from height.

Contributions: It was discussed in central safety committee and it was decided to have three bay tarpaulin covering platform where skilled manpower will be engaged instead of driver to put fall protection device and put covering on finished goods in a safe manner.

Implications: After construction of this shed, all outgoing heavy vehicles on which tarpaulin covering is required are coming to this shed and tarpaulin is being covered in a safe manner leading to zero accident during the same.

BEFORE	AFTER
	
DRIVER ON THE TOP OF TRAILER POSING FALL FROM HEIGHT HAZARD.	**SKILLED MANPOWER DOING TARPAULIN COVERING ON A SAFE PLATFORM AFTER WEARING SAFETY BELT.**

Implementation Mechanism to Minimize Risk of Falling from Top of Bulker

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Raw materials and finished products of lime grinding plant are transported by bulkers. For material loading into bulker, opening and closing of bulker hatches was done manually by a worker climbing on top of tanker and removing or installing securing bolts of hatches by spanner.
Following hazards were encountered:

- Without the proper prevention or protection, simply standing on the top of the tanker puts the workers at risk for serious injuries from a fall.
- Falling objects like bolts, nuts and hatch cover from top of the tankers.
- Silo tanker truck is moveable and there is no proper anchorage point for safety belt.

Development and Evolution of the idea: Earlier near misses were being observed while climbing above the silo tanker, however no injury or property damage took place because harness was anchored with silo tanker ladder, but there was a potential risk of fall from height which could cause serious injury. To mitigate this risk, a team has been formed to investigate the near miss and they have come up with a suggestion to make staircase side of the loading bay so that risk of fall will be eliminated. Team has erected separate staircase with landing platform to go above the bulker top without any difficulty and opening the hatch bolt. Thus, the crew man can get down in a safe manner.

Digital & Technology driven Safety Excellence at Tata Steel

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Tata Steel has been on a multi-year digital enabled business transformation journey intending to be the leader through adoption of digital technologies. We have introduced many digital and technological driven initiatives to facilitate Safety Excellence Journey for achieving zero harm.

They can be described as under:

- **Ensafe** – IT portal for safety lead and lag indicator, reporting and investigation of incidents, data base insights generation through data analytics.
- **General Document Control System (GDCS) –** Repository of safety standards, field implementationguides, safety guidelines, standard operating procedures and maintaining its validity as per QMS.
- **Contract Labour Management system (CLM) -** Repository for contractor workforce database (medical, identity, and safety pass records).
- **E-Permit -** Digital version of work permit system for reduction of cycle time and paperless linkage with positive isolation, connected workforce and other permit requirements for jobs.
- **Connected Workforce -** Real-time workforce tracking system to ensure entry of authorised and certified workmen into designated facility and alerts for workforce in hazardous areas.
- **Talent Pro -** Used in safety domain for effective dissemination of safety standards through e-learning modules.
- **SAP EHS Module -** SAP based master data for Process Safety management and cross calibration of risks across similar facilitates through Recalibrated Risk Matrix.
- **Process Safety Performance Indicator (PSPI) -** Digitalization of dashboard for effective control of process parameters.
- **'SURAKSHA' Platform-** Covid-19 digital safety tracks using IoT based people tracking to monitor and control covid appropriate behavior and workforce covid risk profiling.
- **BriefCam -** Artificial Intelligence based Video Analytics for Realtime alert, Incident analysis and investigation for Road Safety.
- **Safety Leadership Development Centre (SLDC):** Technology based state of the art facility for Safety training of TSL workforce.

Going forward, Tata Steel is focusing on capability development through digital interventions, improving digital capabilities in process safety, risk elimination / mitigation through robotics and technological solutions, connected workforce and connected processes including analytics based predictive models for risk management at workplace.

Keywords: Digital initiative, safety excellence, risk management.

Hook Vision – A New Way of Handling Liquid Steel

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Liquid steel handling via electrically operated cranes (EOT) cranes is the most hazardous work in steel industry. Here, just like moving buckets of water, ladles filled with liquid steel are transported from one place to another via EOT cranes in daily operations. Ladle is picked up by crane only after correct engagement of both of its hooks with the ladle's handle. But due to inherent crane design, one of the hook is partially visible to crane operator at crane cabin and for proper engagement between crane hook and ladle handle, he/she relies on the crew's confirmation who is stationed at ground for this job. Any error in this confirmation will lead to liquid steel spill over and ground crew being in its vicinity, can lead to catastrophic events. So, there is a need to think of handling liquid steel differently.

The present paper describes an innovative system installed in Tata Steel, Jamshedpur which provides a virtual eye to both the crane operator and ground crew through which crane can be tele-controlled in a safe way during liquid steel handling. Here, two high resolution cameras focused for both sides' hook & handle engagement area were mounted at each pick up location on ground and a high bandwidth TCP/IP network was established. Through this, live vision based Graphical User Interface (GUI) for viewing the engagement is made available to both crane operator in cabin and crew in centralized location. Both the UIs are so intelligently designed such that as the crane navigates to a different pick up location, video stream gets automatically switched to the sight of that location without any latency in image transmission. So, the ground crew is completely removed from the steel handling area and hook engagement is confirmed through the automated vision stream.

Self-guided Movable Safety Guard at Induction Furnace Crucible

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Induction furnaces are an integral part of ductile iron pipe manufacturing process. The cast iron produced from blast furnaces is superheated followed by chemistry adjustments in the induction furnace.

The cylindrical design of the induction furnace requires a concrete platform to work on it. The furnace hinged at the front tilts and moves up to pour out the molten metal into transfer ladles. This movement creates a gap between the furnace body and the concrete platform. Hence, this can cause a fall hazard, which is a high risk to anyone in the vicinity of the platform edge.

Fabrication of a permanent guard around the concrete platform would cause hindrance to other working activities like ferro-alloy charging, metal pouring, etc. The concept of a movable safety guard was implemented, all four crucibles having inbuilt movable safety guards to protect the fall of people. But after 3-4 years of operations, frequent malfunctioning of both the damping cylinders disabled the upward movement of the guard.

The non-functioning of the inbuilt safety guard and costly damping cylinder became a challenge to address. It was substituted by a guard (designed in-house) with the movement unchanged with some changes in the design. In place of a MS 5 mm plate, it was made up of ERW pipes resulting in a frame which was much lighter compared to the earlier one. Two 100 mm MS channels were placed on both sides to guide and control the up and down movement. The upward movement of the guard was actuated by a couple of rollers and dead weights hanging at the top and bottom end of a lever respectively. The downward movement was actuated through the self-load of the crucible platform. This is easy to maintain as no external active energy source is required.

The fall hazard could be eliminated from that area of the platform, and this further improved the morale of the workmen. Productivity improved via ease of operation and maintenance and the risk of fall from height was mitigated.

Excellence in Construction Safety

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Construction sites are always a hotbed of high risk jobs and several man-machine interfaces. On one side, it involves movement of heavy mobile equipment whereas on the other side, there is massive material handling. Tata Steel has also witnessed serious injuries in construction activity during modernization and expansion period. Various risk management initiatives at construction sites could minimize the number of incidence. Competency development of construction employees is also a major intervention.

The Three Es Concept:

- **E**ngineering solution
- **E**ducate (Competency development)
- **E**nforcement (Audit and inspection)

To achieve zero harm in construction area, a breakthrough initiative was required. This 3-E concept gave a new horizon in designing safe workplace for our construction engineers. Engineering solutions have been introduced in excavation and other activities.

Excavation: This activity is the most challenging field of construction safety especially in brown field projects. Safety and engineering standards are available for a safe execution of excavation process; however, compliance of these standards always needs special attention of site management. With procedural and engineering solutions, nowadays excavation sites are made safer. Steel trench box is a breakthrough in this regard.

Steel trench boxes are a fast, safe and effective way to shore up trenches and shield employees from a potential excavation collapse or cave in.

Model Construction Site: Construction activity involves many hazards at one single site hence you need to implement proactive measures in a bundled form which take care of many hazards with a single effort. Model construction site concept uses "E- Enforce (audit and inspection) and Educate combinedly. A detailed checklist is prepared and site-in-charges are trained on it. Deployment audits are conducted. Sites having high score in this model see less injuries in practice. This concept address electrical, physical, and construction hazards and ensures legal compliance as well.

Contractor Safety Management: Ensuring Sustenance of Performance

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Tata Steel Initiated Contractor Safety Management System to improve its safety performance. A detailed guideline was made for various rules and procedures to be adopted for screening of qualified vendors. This standard focused on managing the high-risk job service providers, as they conduct most of the safety critical jobs in the plant areas. It was expected that by addressing the safety systems of these vendors the major risks will be taken care of.
This system started giving good results initially and seemed to be in line with expectations. To promote the high performing vendors, some incentivization schemes were also launched. 4 and above star rated vendors get audited in 2 years as per incentivization.
It was being noticed that the lag indicator performance of these vendors was declining, and many safety observations were being noticed against them frequently. This was a matter of concern and was not a good indication.
On analysis of the situation, it was observed that by increasing the periodicity of audit (2 years in place of 1 year) the vendors tend to relax as they had to face the audit after 2 years and this was resulting into poor site safety performance.
To tackle this issue, a change in the scoring pattern was introduced. As per this change, the section 2.0 of the standard audit questionnaire which talks about deployment of safety standards at site was decided to be audited 5 times in a year through different stakeholders. The average of all these 5 audits and the external audit will be taken as final marks of section 2.0 during the final assessment. Thus, the vendors will be continuously maintaining the site safety standards.
This is expected to give good results.

Usage of Robotics and Digitalization to Improve Safety in Rolling Mills

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Background: In rolling mills, human-machine interface is inevitable. This poses a major risk to people workingwith or around the machine. Thus, the challenge is to ensure the human-machine interface should not be the cause or source of injury to the employees. Over the years, several safety initiatives were initiated in rolling mills to minimize human-machine interface and have been successful in reducing the injury potential hazards, still we couldn't achieve our zero harm objective at rolling mills.
Problems: ln rolling mills, major causes of the injuries are moving machinery and material handling. As a process requirement, people work near the running equipment, like strip surface visual inspection activity in which moving equipment decelerates or stops intermittently but machine power can't be isolated. Injury threats always exist in such controlled stop activities. Similarly, in material handling activities at rail and road loading points people are exposed to serious potential hazards like manual wagon door operation, finished goods lashing and unitization activity on wagon or trailer beds.
Contributions: Usage of smart technologies as safety barriers helped us in reducing high potential hazards. Intrusion detection sensors, safety laser curtains, AV alarms, AI enabled CCTV surveillance are few examples which are used as safety interlocks in running equipment. Similarly, mechanized wagon door operation, smart drop gate sensors, annunciation systems helped in safe movement of wagon and EOT cranes at loading points. These are a few examples in material handling activity.
Implications: With usage of these technologies M2M (machine to machine communication) and IOT (internet of things) are integrated to enhance safety features in moving machineries. At Tata Steel, now we focus on "Safetyby Design" philosophy with the help of these smart technologies.

SAP based Interlock Bypass Management System

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Interlocks in any hazardous process ensure that any threat inherently present in or externally impacting the system are deflected away before any harm to the people, asset or environment is caused. They also bring the risks of running a hazardous process within the acceptable criteria of the organization. Such interlocks must always be functional. However, in some critical scenarios, bypassing such interlocks becomes absolutely unavoidable. Some of such scenarios are process trials, malfunctioning of components during high production requirements, maintenance requirement, etc.

To avoid any mishap due to such bypass, the entire process of requisition of bypass, approval, execution and restoration of interlock is digitally recorded in SAP system. Specific persons are authorized in the system as per their hierarchical position for all steps beginning from requisition to restoration. The justification and mitigation plan for bypass has been made mandatory to ensure adequacy of requirement and risk tolerance. In case, the interlock could not be restored within the expected time of restoration, this system forces the requestor to take this bypass through a temporary management of change which requires an exhaustive risk assessment of bypass and approval from higher management. A system enabled review system enables the management to review the requirement and risk mitigation plan for the bypass which further improves the effectiveness of the system.

This system not only provides the user a real-time access to bypass management system but also triggers reminders for any interlock bypass due for restoration. A communication system linked with this system informs all stake holders about the changes.

Overall, this system prevents the user from committing mistakes while bypassing interlocks. Also, it has improved the compliance of interlock bypass guidelines inside the plant. As a result, significant reduction in process incidents related to interlock bypass in the plant has been observed.

Process Safety Improvement in Ladle Teeming Operation at Caster-through Inherent Safer Design

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Inherent safer design (ISD) is a philosophy for addressing safety issues in the design and operation of facilities that use or process hazardous materials. When considering ISD, the process engineer tries to manage process risk by eliminating or significantly reducing hazards. Often, the traditional

approach to managing process safety has accepted the existence and magnitude of hazards in a process, and incorporated engineering and administrative controls to reduce process risk. Where feasible, ISD provides more robust and reliable risk management, and has the potential to make the process simpler and more economical by eliminating the need for expensive safety systems and procedures.

ISD addresses the immediate impact of single events on people, environment, property and business. In a chemical processing plant, this generally means the immediate impacts of fires, explosions and the release of toxic materials.

Inherently Safer Design Strategies

Strategy	Examples
Substitute	Replace material with a less hazardous substance.
Minimize	Use smaller quantities; eliminate unnecessary equipment; reduce size of equipment or volumes processed.
Moderate	Use less hazardous conditions, a less hazardous form of material or facilities which minimize the impact of a release.
Simplify	Design facilities which eliminate unnecessary complexity and make operating errors less likely.

Following the simplification strategy, auto tundish level control system was established at CC3, LD shop#1 which was earlier done manually by teemer sitting beside turret with hazard of liquid steel. Events like liquid steel spillage due to mishandling by EOT crane operator or due to ladle through may have exposed the teemer, increasing the probability of an injury. ISD approach helped to automate the slide gate operation and the teemer was relocated to control room thereby reducing the risk. Slide gate operation was automated based on tundish weight level. The auto tundish level control had further benefits as listed below.

- Safe teeming operations.
- Constant tundish level which ensures less erosion of refractory.
- No fluctuation in casting speed of the strands, which was due to fluctuating ferro static pressure with fluctuating tundish level.

POSTER PRESENTATIONS

Management of Change – A Journey Towards Risk Mitigation

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Background: Process Safety Management focuses on preventing catastrophic incidents and improving the process safety performance of the organisation by effectively managing process risks. Along with standard operating procedures and guidelines, operational excellence is achieved through systematic and thorough analysis of process, asset, operational parameters and control measures.

Management of change (MOC) helps ensure that changes in process do not inadvertently introduce new hazards or unknowingly increase the risk of existing hazards. The process includes recording changes, risk assessments, review and approvals prior to implementation.

Problems: Change is good if managed properly and helps us to improve safety, productivity, quality, cost, environment. However, all changes inherently entail varying quantum of risk and if not managed properly, may lead to unforeseen events. A study has found that 80 % of all large-scale incidents can be traced back to failure in the MOC (Gambetti et al., 2013).

Contributions: MOC is defined as the process for evaluating and controlling modifications to a facility's equipment, design, operational practices prior to implementation of the change. The MOC system gives a facility the confidence to implement change safely and continue to operate safely as the risk arising from the change has been analyzed and mitigated.

Implications: In the company's process safety journey, it has achieved zero red risk process incidences (due to non-compliance of MOC) through an effective change management system, which has evolved over the years via a wide range of learning.

An effective and efficient change management system in an organization not only improves its safety performance but is also representative of the maturity of its safety culture.

Ensuring Boiler Operation Safety through Remaining Life Analysis

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Boiler operation is a highly hazardous activity and maintaining boiler in good health is very important for any manufacturing unit. Although scheduled maintenance of the boilers is done under supervision of boiler inspector, health of boiler is assessed through Remaining Life Analysis (RLA). There are two – 4 TPH and 5 TPH 3 pass smoke tube CO Gas fired boilers at Tata Pigments. The boilers generate LP steam for Tata Pigments process requirements. Boilers are running for 20 years in Tata Pigments and to assess the health of the boilers the RLA of these vital installations was taken up by engaging the OEM.

RLA study was carried out for the 5 TPH Boiler at Tata Pigments as per guidelines laid by Indian Boiler Regulations IBR 391, and OEM guidelines. RLA team carried out the onsite study from 20/08/2021 to 24/08/2021.

Following boiler parts inspected during the analysis:

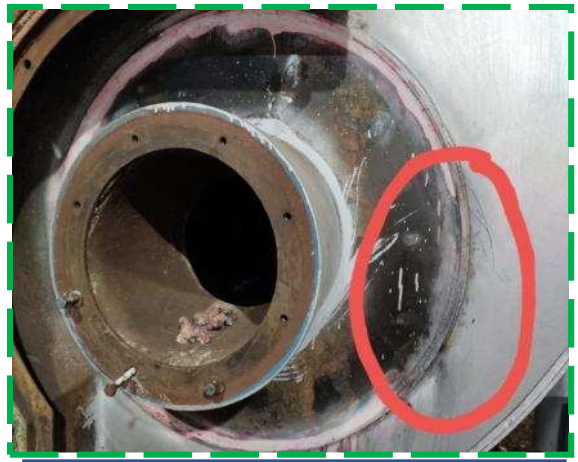
- Boiler tubes
- Tube plate and tube to plate weld joints
- L & C weld seams of furnace and shell

Methodology for testing:

- Visual Examination
- Magnetic Particle Inspection
- Dye Penetrant Testing
- Metallography in-situ and replication
- Ultrasonic thickness measurement
- Hardness test

During magnetic particle inspection, crack was observed in boiler shell welding in burner side. Subsequently welding was done and again MPI testing done to check the welding. If the welding crack remained undetected, it could have propagated along the shell, causing heat loss from boiler shell. In worst case scenario, boiler could burst causing huge damage to people, property and environment. This was avoided due to conducting RLA at the right time.

Crack found after MPI



Slip, Trip and Fall Prevention: Balance

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Falls continue to be one of the leading causes of injuries. In fact, there were more than 9.1 million people injured by slip, trip and fall injuries in 2014, according to the National Center for Injury Prevention and Control.

- Balance can help keep a slip from becoming a fall. Balance should be addressed when considering the aging workforce; after age 30, the muscles for balance begin to weaken.
- Balance can be maintained with an active lifestyle, but sitting at a desk for more than eight hours a day, driving and sitting in the evenings after work do not contribute to an active lifestyle.

Discussion: Slips, trips and falls are not industry specific. Every industry, including manufacturing, construction, energy, healthcare, retail and office environments, has individuals that have been injured from falls. Walking surfaces, housekeeping and trip hazards may cause slips, trips and falls. Other, not so obvious, factors may include the individual's vision, hearing, medications, fatigue or illness. It is possible to removethe physical hazards that cause the falls, but the human factors remain. What can be done to help improve balance?

The ability to balance is dependent on the vestibular system, the somatosensory system and the visual system. The vestibular system (inner ear) regulates the equilibrium, providing directional information to the brain. The somatosensory nerve receptors are related to balance through touch, pressure, position, and movement dependent on the muscles, joints and skeletal system. The visual system addresses spatial location and balance. Degeneration of any of these systems as a result of aging, eyesight, sedentary lifestyle, fatigue or illness can affect balance. The good news is that the balance system can be improved. In an effort to provide a safe work environment and reduce injuries, simple timed balance tests can be completed to help individuals understand their current "balance age." Daily exercises can then be introduced to help improve their ability to balance. Monthly timed tests can help individuals see the improvement in their balance skills.

Guidance: Balance tests — Static balance can be tested with a hard floor surface, bare feet and a stopwatch. It is important to have a wall, chair or railing nearby to prevent falls. At any point when an individual has concerns about balance, the test should be stopped and he/ she should seek medical attention. These tests are not medical exams, but are an objective method to measure balance and compare the balance data with the slip, trip and fall loss experience.

The Romberg test, better known as the sobriety test, can be used to determine balance. It was determined that the three systems (vestibular, somatosensory, and visual) must work together to maintain balance. The progression for the balance tests go from:

- Standing with feet together.
- Standing with one foot in front of another with the heel directly in front of the toe.

Automated Raw Material Handling System (RMHS) Application at Cement Mortar Lining Process of Ductile Iron Pipes

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The advantages of ductile iron pipes (DI Pipes) are high corrosion resistance, toughness and the ability to withstand extreme conditions needed for various engineering applications. One of the prime business verticals of Tata Metaliks is the manufacturing of DI pipes.

The finishing department, an integral part of the manufacturing process of DI pipes has a method to provide an internal lining to the pipes through the Cement Mortar Lining process. Sand and cement are two of the most essential raw materials for the finishing department towards manufacturing of DI pipes. Thepouring operation of sand was previously done manually. This manual pouring operation of sand was causing fatigue to the workmen leading to serious safety concerns.

Instead of manual pouring of sand into the bunker, a new automated system was introduced. The required sand is transferred to the sand bucket by a mobile equipment. A continuous vibrating automated mechanism in the sand filling station feeds a requisite quantity of sand into the sand bunker for preparing the mortar used in the internal lining of DI pipes without any manual intervention thereby improving safety, accuracy and productivity.

To summarize, this automation resulted in elimination of any man-machine interference, thereby improving operational safety. Furthermore, it also resulted in manpower reduction yielding quantifiable benefits. Consequently, there was improvement of productivity via reduction of workmen fatigue and manpower reduction by optimization/reduction of manpower (~96,300+ man-hours per annum).

Enhancement of Safety for Pedestrians Crossing Road near Traffic Signal

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While crossing the road near traffic signals, few pedestrians tend to ignore the indication of the traffic signal. There have been many near misses captured at traffic signals wherein dashing incidents between the pedestrians and the vehicles moving on getting green signal could have occurred.

To improve safety culture amongst pedestrians, a pilot trial of buried zebra concept was taken at L Town Gate in Tata Steel, Jamshedpur. This consisted of a set of LED lights synchronized with the traffic signal buried inside Road.

Now, people stop and wait for their turn if they notice a red LED glowing near their feet. When their turn comes, the LED glows green thereby allowing the pedestrians to cross the Zebra safely.

Resources required:

- Polycarbonate
- Mild Steel Case with Powder Coated Paint
- Water Resistant Sealing

Key Features of the Buried Zebra:

- Synchronized with pedestrian traffic lights.
- Surface is anti-slippery and rubber spring can bear the pressure of a running car over the product.
- Best heat sink with unique buried ventilation holes.

Fool Proofing:

- Unique circuit design, damage in 1 LED chip will not impact the performance of other LEDs.

- Use of frosted tempered glass gives Anti-high strength compression and vibration.
- IP67 Tri waterproof treatment.

As Cast Sample Breaking Machine

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The ductile iron pipe production process requires annealing as a heat treatment operation. This process imparts the ductility to the brittle pipes by dissolving the pearlite into ferrite. This calls for a microstructure check both before and after annealing. The check is done to ensure the heat treatment process is adequate.

First, microstructure samples are collected from the pipes in As Cast condition before annealing operation. The pipes at this location are hard (240 BHN or above), brittle and have a temperature of 400 °C or above. Hence the samples are to be broken, and not cut (using conventional cutting machines). Thus, this job is considerably difficult and unsafe.

The samples were broken using a traditional tool (a Class 1 lever). This made the person collecting the samples vulnerable to high heat. Moreover, in case of thicker pipes he had to apply a greater amount of force which made the whole activity strenuous and enervating.

An automation was done in the area where the force applied by the person was replaced by a hydraulic jack. The jack was mounted on an arrangement which can move to and fro to adjust as per the location of the pipe. The person can now stay at a safe distance from the pipe, and can operate the jack to get the samples.

A Systematic Approach of Improving Contractor Safety Performance – through Vendor Partner Safety Annual Business Plan

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Background: Iron Making Division in any steel making industry consists of above 50 % of the total contract manpower engaged in high-risk job. We had recorded 3 LTIs and 9 FACs in FY'21 at IMD, which were contributed by vendor partners alone. All processes are defined as high risk and all the high-risk vendors have been prepared for star rating process, they have prepared an annual business plan for improvement of safety in their specific areas which has resulted in reduction of injuries.

Major Drawbacks in Vendor Documentation:

- Safety policy to be updated.
- Safety principles need to be developed.
- Safety manual to be updated.
- 100% JHA to be prepared as per SOP for all the sites.
- Audit review system to be developed for high severity (4 and 5).
- Job execution plan and method statement need to be developed.
- Training evaluation system to be developed.
- TNI to be carried out for all the sites.
- Compliance on points captured from employees during proprietor line walks, toolbox meetings and mass meetings to be developed and documented.
- Housekeeping audit plan to be developed.
- Self-initiative procedure exists, but the suggestion received are not as per the employees in the organization.
- Campaign plan with theme to be developed.
- PDCA for reduction of unsafe act and practices to be developed.
- Change/ requirement of PPEs as per SOP not available. Revision of SOP based on PPEs feedback not available.
- Regular review of tools and tackles quality and requirement and necessary changes as per SOP not available.

Contributions and Implications:

- Continuous improvement in the system based on feedback of audits - improvement in objective (leading and lagging indicator) and evidence of continual improvement trend system is developed.
- Safety, a mandatory requirement for engaging all employees is mentioned in job description, appointment/employment contract clearly and workers abide by it.
- Job execution plan and method statement prepared for 70 % activities.
- Training feedback, TNI and evaluation system developed by all vendors.
- Compliance on points captured from employees during proprietor line walks, toolbox meetings and mass meetings to be developed and documented.
- Model work places developed by vendor.
- Monthly improvements are captured and displayed at site.
- Encourage employees to capture near miss cases.

Job Cycle Check through Risk Assessment

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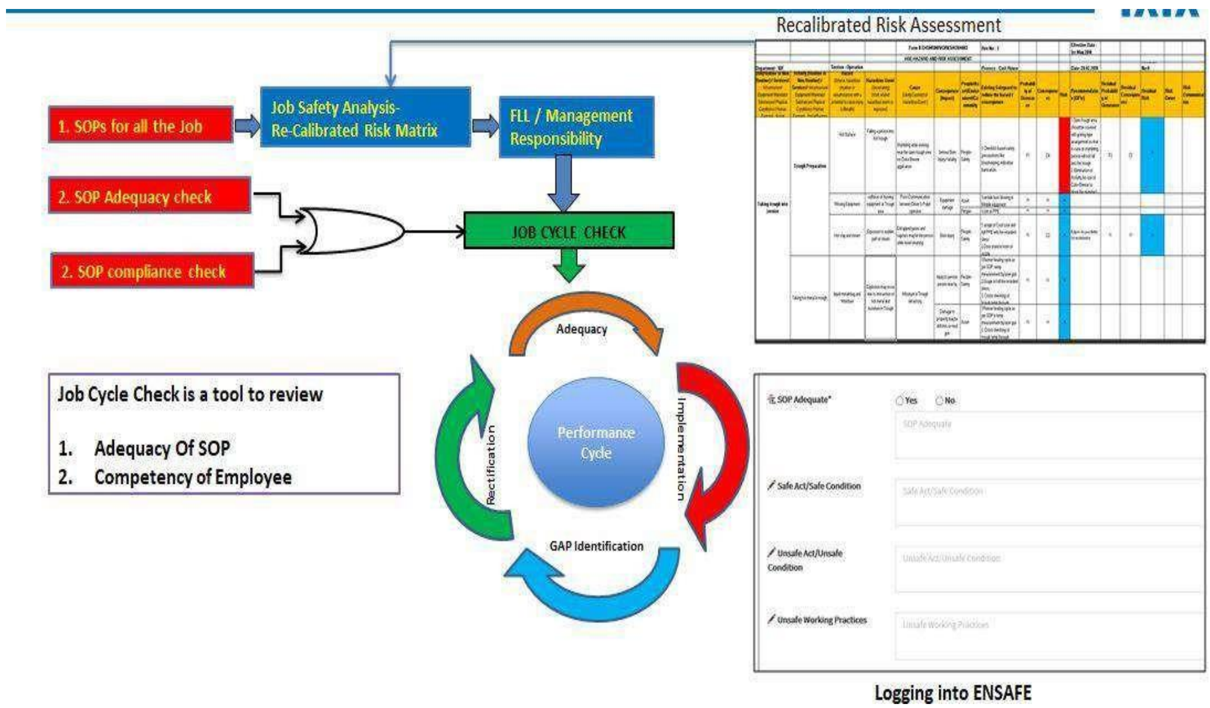
The aim of this work is to identify those potential hazards that could be the risk of job place accidents and to take preventive measures to reduce the intensity of accidents. In order to minimize the rate of hazards pertaining to high risk operation, appropriate safety arrangement is to be employed for the safe working environment of the workers. In this regard, Job Safety Analysis (JSA) or Job Cycle check (JCC) technique is conducted to identify potential hazards on each job place. JCC is a tool to review the adequacy of SOP and competency of employees. It also creates connection among concerned operators, workers, job place, task, equipment and tools used and the working environment. The required data for calculating quantitative risk has been collected by direct observation of concerned supervisors recorded at various shifts. After conducting the analysis and assessment procedure, a number of possible preventive measures are suggested and communicated to all the employees engaged with line operation. These techniques are designed to provide information for decision-making processes in all steel industries dealing with manufacturing processes.

JCC and Risk Assessment techniques were conducted that showed highest level of risk with probability, consequence and severity background and compliance of right procedure of job by crew members as well as practical input from working crew to make SOP a working document (do the way it is written and write the way it is to be done).

Thus, continuous practice of JCC through recalibrated Risk Assessment minimizes the risk of high hazards pertaining to high risk operation.



Systemic Improvements in Safety Management System through Near Miss Capturing: Case Study of a Manufacturing Unit of Steel Industry

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Background: Near misses are harrowing close calls that could have been a lot worse, they are incidents that could have happened but did not due to gap in time or distance. While there should be a system to encourage people to record near misses, analysis of the same is also important to bring about the required improvements in safety management system. Latent errors often exist for long periods of time before they combine with enabling conditions to produce a significant failure. Whether an enabling condition transforms a near miss into a crisis generally depends on chance; thus, it makes little sense to try to predict or control enabling conditions. Instead, companies should focus on identifying and fixing latent errors before circumstances allow them to create a crisis.
Problems: Recognizing and learning from near misses does not only require paying attention; it actually runs contrary to human nature. In this case study, we have examined near misses and reveal how companies can detect and learn from them. By seeing them for what they are – instructive

failures – managers can apply their lessons to improve operations and, potentially, ward off catastrophe.

Contributions: This initiative has helped to develop systemic improvements in lock out tag out system. 'Try out' has been deployed in the manufacturing unit and various methods have been used for actually simulating the equipment.

Implications: 'My life is my life' tag has been justified in this initiative as after group isolation lock has been done, contract supervisor puts his personal lock on the box. Relevant documentation has been implemented in the control room. 'Try out' has been done either by operating the equipment through local switches or through actuating it by DCS screen in control room.

Robotics Application in the Finishing Operation of Ductile Iron Pipes

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The advantages of ductile iron pipes (DI Pipes) are high corrosion resistance, toughness and the ability to withstand extreme conditions needed for various engineering applications. One of the prime business verticals of Tata Metaliks is the manufacturing of DI pipes.

The finishing department, an integral part of the manufacturing process of DI pipes has taken an initiative to ensure a smooth spigot surface post chamfering. The problem statement was to produce a chamfered edge with no burrs on the spigot end. These burrs if present create a problem in smooth fitment with the gasket during on-site pipe laying. Primarily, deburring is performed manually by workmen equipped with appropriate tools and PPE, which makes the process unsafe. There is a direct man-machine interface wherein the operators standing next to the rotating pipe perform this activity. Furthermore, strenuous working for a long duration affects the health of the taskforce leading to reduced productivity.

After a lot of brainstorming and detailed analysis, we came to a probable solution that involved performing the deburring process and removal of sand contamination by using an industrial robot. Productivity loss due to fatigue was eliminated and man-machine interference was reduced to a great extent. Use of industrial robots improves accuracy, productivity and efficiency in a consistent manner.

Application of robots has a significant impact on manpower cost, productivity and safety. Manual deburring operation and cleaning of the socket profile has a high risk of injury thereby adversely impacting safety of the workforce. Use of robots eliminates most of the human intervention thereby improving operational safety. Also, it delivers a consistent and accurate operation resulting in a high degree of dimensional accuracy. This application has resulted in improvement of productivity as well as manpower cost reduction via optimization/reduction of manpower (~ 26,000+ man-hours per annum).

Safety Competency Assessment of Contractors

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Nowadays all principal employers are more or less dependent on contractors. By considering the business need, there are different types of contractors associated with industries. Usually types of contractors are:

- Manpower supply type contractor
- Service providers
- Expert supervision type
- OEM and supplier

In every case they are the first person who face the risk at workplace. Unfortunately, their safety competency level is not up to the mark. Hence safety competency must be assessed at each stage of contractor safety management. Usually contractor safety can be managed in six steps namely

- Contractor selection
- Contract preparation
- Contract award
- Orientation and training
- Managing the work
- Periodic safety evaluation

How safety competency can be checked at different stages?

Sr. No.	Step	Key elements/checkpoints
1	Contractor Selection	• Pre-Qualification for Registration. • Identify contractors who comply with requirement of standard safety management system. • Evaluation of contractor's safety performance before registration.
2	Contract Preparation	• Identification of scope of work and inclusion of specific safety clauses based on hazards. Assessment of the proposed contracted job.

3	Contract Award	• Thorough and effective communication and review of contract safety specifications at bid, pre-bid and pre-award meetings. • IT-based system may be used for pre-bid meeting.
4	Orientation and Training	• Training on job specific safety requirement, skills, health and hygiene.
5	Managing the Work	• Deployment of right resources as per contract specification and different activities to manage safety at site. • Supervision.
6	Periodic Evaluation	• Establish the process and procedure for safety. • Performance evaluation and feedback to vendors and procurement. • Rewards and consequence management to ensure that the contractor is either allowed to continue working or is removed due to poor safety performance.

Minimizing Risks in Loading-Unloading Activities in Steel Industry Development of Model Loading-Unloading Points

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Background: Sinter plants agglomerate iron ore fines (dust) with other fine materials at high temperature, to create a product that can be used in a blast furnace. The final product, a sinter, is a small, irregular nodule of iron mixed with small amounts of other minerals. The process, called sintering, causes the constituent materials to fuse to make a single porous particle with little change in the chemical properties of the ingredients. The purpose of sinter is to be used in blast furnace to provide iron ore for conversion into molten iron.
Problems: Raw materials and finished products need to be transported to different locations in this process. Limefines, base mix, sinter, coke fines, etc. need to be transported through dumpers and there are specific points for this. These points involve manual interface of fixing pipes, getting on top of heavy vehicles, going to rear side of the vehicle, etc. Due to many blind spots created during

these activities, there is always a high risk of persons getting hit by heavy vehicles. Steel industries have many fatal/serious injury incidences in these areas.
Contributions: This initiative has helped to develop these areas based on a standard checklist. The checklist involves elimination of interface of heavy vehicles with pedestrians, checking of physical condition of vehicle by driver, blind spot elimination and fall protection in case person moves to a height for any operation. Additionally, there are one point lessons and dos and don'ts related to these activities and also visual standard operating procedures.
Implications: 16 model loading points were developed where standard platforms were developed, signs were displayed and blind spots were eliminated.

Improvement in Scrap Charging Activity in Process

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In the precipitation process iron salts react with caustic soda in the presence of air or oxygen. This process is controlled by temperature, pH, purity, concentration, mix design and reaction velocity. MS Iron Scrap is charged in reactors for solid growth. It is charged by using electric hoist or orange peel grab bucket. The Red Oxide Growth tanks are being charged using electric hoist while the orange grab peel bucket was used for charging in Yellow Oxide Growth tanks. In the month of September 2019, during maintenance, the sling wires were badly damaged and there was also a need for replacement of the same equipment due to its dilapidated condition.
The following near misses could have occurred due to this

- The entire structure of orange grab peel bucket could have fallen on the working platform damaging property to a very great extent.
- It could harm the persons working in the area very severely.

To address the above concerns, in the year 2021 it was finally replaced with an electric hoist for charging which not only saved time of charging but also improved the safety aspect to a great extent. This has improved process efficiency as well as curbed a lot of incidents that could have occurred due to the the orange grab peel bucket's condition.

This was a process initiated effort which bore fruitful results.

Material Handling of Jumbo Bags in a Safe Way

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Development and Evolution of the idea: Earlier incidents were being observed during handling of jumbo bags from godown to loading in silo tankers. Suddenly handle of the jumbo bag got broken due to non-centric load and material got spilled, causing a lot of dust emission and the person was also affected by contact with dust. The idea was initiated to mitigate the risk in operation and ensure a healthy and safe environment inside the plant and also to look after the health of the people. An idea was developed to make a special type lifting tackle to lift the jumbo bag with centric load which could be used in forklift and EOT crane after investigation by the safety and operation team. **Challenges faced and mitigated**: After the incident took place the investigation team did the brainstorming and after taking feedback from line managers and contract employees, it was decided to make such a lifting equipment which could be used in both forklift and EOT crane. Also, we were facing challenges in proper gripping with fork of forklift. The team has fixed bolts at places so that proper fixing with fork of forklift can be done and also provided U clam above the tackle so that it can be use in EOT crane. Load testing of this in-house developed special lifting tackle has also been done by third party.

Replacement of Canlock Coupling with Stronz Coupling for Ensuring Safety in Lifting Areas

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Development and Evolution of the idea: Earlier incidents were being observed with cam lock coupling while unloading raw material. During unloading of raw material, male coupling came out and due to pressure inside the silo tanker a lot of dust emission was observed and the person was also affected by contact with dust. An idea was initiated to mitigate the risk in operation and ensure a healthy and safe environment inside the plant and also to look after the health of the people. Idea to replace the cam lock coupling with Stronz was developed after investigation by the safety and operation team.

Challenges faced and mitigated: After the incident took place the investigation team did some brainstorming and decided to replace the entire cam lock coupling from LGP and customers' end to mitigate the slip out risk. Storz coupling received was having different thread standards which didn't match with BSP thread. For each coupling a nipple with matching thread was made in lathe and installed in all the lifting lines.

Before

After

Technological Interventions upheaving TSL Safety Journey

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Tata Steel's vision, "We aspire to be the global steel industry benchmark for Value Creation and Corporate Citizenship", rests on making a difference through its people. This is derived from its 'people first' ethos; hence, the safety and wellbeing of its employees are of utmost priority.

Be it the deployment of process safety Centre of Excellence (COE) framework or developing capabilities through the digitally enhanced, demonstration-based training at Safety Leadership Development Centre or ensuring business continuity during emergency situations through Tactical Centre, which has real time feed of all critical process parameters through cameras, we strive to leave no stone unturned to achieve our ultimate objective of 'Zero Harm'.

A tableau-based, online Process Safety Performance Indicator (PSPI) dashboard was introduced, incorporating all process safety related lag and lead indicators. All available IT systems (SAP, ENSAFE, Process Data, L1/L2 systems) with their various process safety parameters were integrated into the common dashboard, business rules formulated against them and real-time alerts made a key component. 'Connected People' initiative was launched to ensure safe working with near real-time tracking, alerts and QRT (quick response team) protocols. 'Connected People' relies on receptor beacons, a Suraksha card (that the worker carries) and dashboards/alerts, which are generated, monitored and acted upon. 'Connected People', coupled with the e-work permit system, helps analyse the effective utilisation of workforce and prevents workmen from entering hazardous zones.The system proved extremely effective in contact tracing for Covid-19 cases.

Interventions taken to improve road safety, comprising the installation of a radar-based speed monitoring system, Automatic Number Plate Recognition (ANPR) and surveillance-on-road via the Brief Cam software, have enabled TSL to proactively identify violations on road. In addition to that, Driver Fatigue Monitoring System (DFMS) which provides real time alert in case of fatigue symptoms detected in drivers while on driving seat, has enabled us to bring down road incidents.

In coming years, we aim to ensure 100% deployment of multi-level RFID-based access control systems in high hazard areas. foresee site specific concerns using video analytics and mitigate red-risk through deployment of Robotic/Engineering/Digital solutions.

Journey Towards Promoting Safe Work Culture

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"Behavior Based Culture" is the manifestation of safe operations where employees are able to care for themselves and their working environment. Demonstration of safety culture and interdependency of line function can provide harmless operation in any industry. While behavioral upgradation can lift us significantly to safeguard our people, zero harm can be ensured by coupling engineering solution using mechanization, automation and digitization, along with risk based thinking.

While analyzing different incidents, we found that man-machine interfaces are the major bottleneck of achieving zero harm. Accident happens while working with equipment when the eyes and mind are not in line with action, people become complacent and develop fatigue due to performing the same kind of job in challenging environment.

Promoting "Safe Working Culture", we have initiated training on "FELT" leadership for the workforce, mechanize and automate processes where it is in a challenging environment and digitization technology to ease level of operation.

To promote Risk Based Culture, we have migrated from simple HIRA (Hazard Identification Risk Analysis) to HSE (Hazard, Safety, Environment) matrix where all activities are mapped with respect to four parameters (People, Assets, Community, Environment) and developed "Risk Heat Map" for entire organizationsubsequently migrating from red, yellow risk category to blue, green risk category which are within acceptable limit.

Some initiatives and benefits:

#	Initiatives	Benefits
1	Mechanization of Ferro Silicon Addition in Hot Metal	Eliminate high risk and burn injury
2	Pneumatic Hot Metal Sample transferring fromCast House to Quality Lab	Eliminate burn injury
3	Automation in Material Feeding Chute Placement at Raw Material Bunker House	Eliminate fall and collision hazard
4	IOT based Condition Monitoring System for High Speed Rotating Equipment	Eliminate high risk activities, ease in monitoring the machine health

This has resulted in 50 % reduction of first aid cases.

IIM Metallurgy Materials Engineering

THE INDIAN INSTITUTE OF METALS

A Systematic Approach of Engagement Vendor Owner & their Team for Improving Safety, Health & Environment

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Background:

In Tata Steel BSL Sahibabad division, most of the work is done by vendor partners' workforce starting from in process – shifting and transportation of HR Coil for pickling, galvanizing, color coating till finishing to product transportation to customer as per their requirement. All these processes are high risk and earlier vendor workforce priority was production.

Problems: It was observed that vendor work force priority was production only, so in safety their engagement was lacking. They were not much aware about the hazards, risks, and safety issues in their area of work.

Contribution: Vendor proprietors and their cross-functional workforce developed a one month program for their area of work on safety, health and environmental issues along with productivity. Vendor workforce was engaged and they were made capable to find out hazards of workplace and their mitigation processes. This program helped in educating workers about the unsafe activities they were doing in workplace.

Implications: This program helps in increasing awareness and engagement of vendor workforce in developing safety culture by identifying the safety, health and environmental issues in their workplace. It will also involve vendor properties to run campaigns at workplace and get involved in all activities related to improve safety culture. This initiative helps proprietors and vendors' workforce for taking ownership in improving safety, health and environment issues in their area of work and improve productivity.

Internal Material Handling System to Minimize Injuries

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Material handling is a highly hazardous activity in our plant. Lots of unsafe acts and conditions are observed in daily activities. Around 40 % injuries happen during material handling. About 2/3rd of manufacturing cycle time is spent on handling. To reduce the injuries during the activity, lot of discussion was done, and following actions were taken that include principles and physical elements used for designing a material handling system. To explore how an internal material handling system can be improved to guarantee a better delivery performance, painting yard was shifted near the manufacturing unit. About 2-3 Crores of one-time investment was done, but transportation cost now is insignificant. Time was reduced and productivity increased from this implementation.

An efficient internal material handling system minimizes injuries to the workers and at the same time makes sure that materials and products in the system are not damaged or contaminated.

Combined analysis of the findings from the empirical study and the extensive literature review helped to identify the problems faced in an internal material handling system of the company. This was followed by identifying ways of improving material handling system and thereafter, suggestions were given targeting enhancement of the balanced performance of the system.

In conclusion, the findings indicate that improvement of an internal material handling system does not only depend on improving the physical attributes of the system; far from it, it is more dependent on having an efficient and effective information system. Another factor that came to light is that there should be a proper integration of the material handling system and the workers operating the system.

Occupation Exposure to Covid-19 for Dental Care Workers

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Objectives: Occupational characteristics of dental care – including closed environment, proximity to staff and patients and the use of aerosol generating procedures – put workers at high risk of Covid-19 exposure and transmission. We describe the frequency of workplace situations that potentially increase the risk of exposure to COVID-19 in dental care compared to other occupations including health care.

Methods: We conducted a cross-sectional study using sociodemographic and occupational data from the 2020 Indian census linked to workplace characteristics from the Occupational Information Network (O*NET) dataset. We assessed frequency of workplace indicators using an intensity score from 0 (low) to 100 (high) from O*NET on exposure to infection or disease, physical proximity to others, indoor controlled environments, standard protective equipment and specialized protective equipment.

Results: In 2020, 87815 Indians worked in the 5 dentistry occupations of interest: dentists; denturists; dental hygienists and dental therapists; dental technologists, technicians and laboratory assistants; and dental assistants. These occupations were routinely ranked in the top 10 of all occupations examined in terms of exposure to workplace indicators that increase the risk of exposure to COVID-19. Dental hygienists and dental therapists, dental assistants, dentists and denturists, rank as the top 4 occupations, in that order, with the highest exposure to disease or infection and physical proximity to others combined.

Conclusion: Compared with other occupations, dental care workers are at a higher risk of occupational exposure to COVID-19. These results support the development of workplace guidance to reduce the risk of COVID-19 transmission and enhance the well-being of the dental care workforce.

Overall, the results of this study suggest that dental care workers are at a higher risk of exposure to COVID-19 at work than those in other occupations.

Learning from Slip, Trip and Fall Incident

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An accident is never desired but it happens because of several reasons. Slip, trip and fall happens widely in daily life and results in injuries. It includes falls due to water, ice or snow, oil, grease, uneven surface, poor lighting, shoe condition and mental absence during physical presence.
Slips, trips and falls can be very costly to an individual and organizations. It may result in minor injuries to major injuries as well as deaths. Even for organization, it accounts for bad safety records, where compensations and lawsuit may be also possible.
There are some very prominent reasons for slip trip fall cases happening at present at different organizations. People are more attached to technology or virtual world. It creates absence of person mentally at the place where he/she is physically. Thus, it is quite important to be present physically as well as mentally at shop floors. Always be very careful while moving at STF prone areas.
People are adopting casual approach in current living styles. They are not connected much with nature. Due to this, our body is deprived of many natural ingredients which are supposed to be inside the body for fit and healthy life. Eg. people are less exposed to sun, which is the natural source of vitamin D. Due to lack of such vitamin the bone strength is weakening and resulting in injuries in body parts even in mild STF incidents.
We must be focused on safety and health in our life. Health and safety are the real wealth and joy of life. We can't live a peaceful mind without them. We should follow ABC (Always be careful) practice in our shop floor/other places. Everybody should contribute to make a workplace STF incident free.

5-G Welding for Safety of Intricate Structures

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Erecting a complicated and intricate design with hollow pipes is always a challenge for metal workers. It sets high risk of failure of structure during and after construction. To manage such risks, a standard process of erection and fabrication is required.

A project was taken to pay homage to Sir Dorab ji Tata with a diamond structure monument at Jamshedpur. For this purpose, "*Tubes Structura*" was used to get the desired shape. The shape was designed at a nearby fabrication yard and then assembled and erected at Sir Dorab Ji Tata Park. This erection, assembling and mounting at the desired place was very challenging in view of safety and mechanical integrity.

For this critical task, the highest standards of welding practices were adopted i.e. 3G, 4G, and 5G welding positions.

In this project, we used 3G, 4G and 5G welding positions. Detail of these welding positions are given below:

3G Downhill/PG Position (Vertical)

It is a vertical-down position used for fillet and butt welds. Welders used the metal from the upper part.

4G/PE Position (Overhead)

It is an overhead position used for butt welds. Welders need to hold the torch below the metal piece. Normally, it is a complex and hard position. Welders must set proper parameters before welding.

4F/PD Position (Overhead)

This is also an overhead position used for fillet welds. Mostly, welder holds the torch at a 45° angle while being below the metal piece and it depends on the pipe/plate positions.

5G Welding Position

5G welding position is used for pipe welding and the axis of the pipe is stable in a horizontal position without turning or rotating. 5G stands for 'groove weld'.

The Project:

Vacuum Attachment Solution for Ductile Iron pipes Handling at Ductile Iron Pipe Dispatch Section

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Since last ten years DI (Ductile Iron) finished pipes are handled with chains and shackles attached with an iron frame, colloquially known as 'Jhapa'. First pipes are hooked manually atboth ends of the rows of pipes, then pipes are lifted and shifted. The hooks need to be manually removed again after unloading which is a high risk job and has a fatality potential.
Through elaborate brainstorming sessions, the dispatch department came up with a creative solution to resolve the issue. Vacuum lifting technology, originally from the Netherlands, is introduced with increased operational efficiency and elevated on-site safety. This operation is not only about 8-12 times faster than the conventional lifting method but also has the ability to mitigate the six directional hazards.
This is the first time in India in DI pipes industries 'vacuum attachment' has been introduced by Tata Metaliks Limited to reduce man-machine interface and elevate utmost safety.
Solution of 'vacuum attachment' has a significant impact on manpower cost, productivity, and safety. Use of 'vacuum attachment' eliminates most of the human intervention therebyimproving operational safety. Also, it delivers a consistent, time saving and accurate operationresulting in a high degree of dimensional accuracy. This application has resulted in improvement of productivity as well as manpower cost reduction via optimization/reduction of manpower (11 loading-unloading points = 22 heads per shift x 3 shift = 66 x 8 man hr
= 528 man hr x 365 days = 192720 man-hours per annum)/man-head (66x365) i.e 24090 x@645/-
= Rs. 1.55 Cr.

Onto Zero Life Style Diseases

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Safety is at the core of everything we do, even while sleeping. Every organization has set the goal of ZERO harm to people, environment pollution and occupational health. A company holds lots of initiatives/drives/campaign and also has a system, structure and mechanism in place to achieve this mission and vision.
Even after all efforts, safety incidents take place and we are involved in unwanted legal and financial consequences and face direct and indirect cost. A study says that 90 % of all workplace injuries caused by worker`s unsafe action or behaviour are due to lack of adequate knowledge, overconfidence, work pressure, stress, etc. Sometimes, people with awareness of safety norms and violation consequence neglect and bypass safe working procedure. What is missing such that they do this? What comes to mind that one becomes reluctant complying with safety procedures?
A baby is playing at home and some oil is seen on floor – the baby can slip and serious head injury

could occur. Anticipating this, we immediately remove oil from floor. Here, our conscious mind sees the situation, our unconscious mind recalls consequences and our bonding with the baby comes from the heart.
At workplace, we believe in the safety system in place, and start job without proper re-checks. Here, only our conscious and subconscious mind works. But as soon as we connect with family and visualize bonding with them, it ensures fitness of entire safety system without delay.
So, three waves in our body work together, conscious mind (what we think), subconscious mind (where emotion lies) and feelings from the heart. Heart feelings connect with emotion and our subconscious mind overrides wills of conscious mind when emotions are high and people react accordingly. A person who ignores safety for self and the others, shows his angle of thinking, where heart feeling connection with emotion is always found missing.

Ratcheting Fatigue Life Prediction of High Strength Low Alloy Steel using Hysteresis Loop Energy-Based Approach

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This investigation aims to predict the ratcheting fatigue life of high-strength low alloy steel (HSLA) with the combined effect of mean stress and ratcheting strain using a stress-strain hysteresis loop energy-based life prediction equation. A series of asymmetric stress-controlled fatigue that is uniaxial ratcheting tests have been carried out using a ±100 KN servo-hydraulic universal testing machine at room temperature. The stress has been controlled in two ways, viz. (i) constant mean stress with varying stress amplitude and (ii) constant stress amplitude with varying mean stress. The obtained experimental results exhibited a sharp reduction in ratcheting life associated with an increase in ratcheting strain, both for increasing mean stress and/or stress amplitude. As the loading conditions have been kept asymmetric, the unclosed hysteresis loops are generated. These shifted towards the positive plastic strain direction, indicating strain build-up in the material cycle by cycle. For the current investigation, the accumulated ratcheting strain has been measured by averaging the maximum and minimum strain induced at a particular cycle. A continuous cyclic softening has been noted till the final failure of the specimens. Proper estimation of ratcheting life is essential for component design to safeguard the structure from early or premature failure. Different approaches can be followed to predict fatigue life, namely the stress-based, strain-based, or hysteresis loop energy-based approaches. Over the past few decades, many stress-based and energy-based fatigue life prediction models were proposed by numerous

researchers to estimate life. In this study, an energy-based life prediction model has been acquired from the existing literature and subsequently modified to reflect the plastic damage that is occurring due to ratcheting fatigue. The newly proposed life prediction equation shows good agreement with the experimental results obtained on the investigated HSLA steel.