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B Sunita Minz
Susanta Sarkar
Surendra Prasad
Nityananda Mondal
Rakesh Kumar Singh
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Editors

Proceeding of International Conference on

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The Indian Institute of Metals
Bokaro Chapter

Proceeding

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(First Edition)

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Preface

The previous three industrial revolutions were all triggered by technical innovations. Currently, Industry 4.0 is a popular term to describe the imminent changes of the industrial landscape, particularly in the iron and steel production and consequently in the refractory industry. The full digitization of industry promises significant efficiency gains. This development has already started to have an impact on the operation of steel plants, when decisions are made based on traceable data. This key note address will present examples of current developments and visions in regards to refractory production, optimization of the supply chain from mining to application in steel plants, and examples of easy accessible decision supporting services.

The International Conference on Refractories in Iron & Steel Industries encompasses the major domain of Refractory engineering and technology in the dynamic world of the present age. The Conference aims to bring together Iron & Steel Industry, Manufacturer of Refractories, Leading academic scientists, Researchers and Research scholars to exchange and share their experiences and research results on all aspects of Refractories used in Iron and Steel Industry.

The lectures have been divided into eight sessions with the following topic. Each session is chaired by a professional who is long term working in refractories related to Iron and steel industries.

Topic 1: Emerging Technology for Refractory in Refractory

Topic 2: Refractories for Iron zone

Topic 3: Refractories for Steel zone

Topic 4: Refractories for secondary steel refining and casting and Quality assurance

Knowing, what enormous work has to be done to organize a conference, organization committee would like to thank the company management of Steel Authority of India Limited for the acceptance of execution, the hospitality for their very involved preparation.

(P K Rath)
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Use of Artificial Intelligence, Machine Learning & Big data in Refractory Maintenance Technology

Prakash Bharati[1, a], Jose Maria Dominguez[2], Jose Torres Alemany[2] and Margarita Alvarez[2]
[1] ALFRAN NRL, [2] ALFRAN
[a] Corresponding author's email: prakash.bharati@alfrannrl.com, domiba@alfran.com, jtorres@alfran.com, mam@alfran.com

Abstract

Refractory maintenance is an integral part of core industries such as Aluminium, Cement, Foundry, Iron & Steel, Petro-chemical and thermal power plants. In the era of Industry 4.0, the maintenance landscape is taking a new shape which is primarily driven by the Industrial Internet of things (IIOT). Industry 4.0 promises significant efficiency gains as well as trigger changes - especially harsh and dangerous working environments of refractory operations [1]. Fourth industrial revolution has gained significant momentum in the recent past mostly driven by rapid development in the field of Artificial Intelligence (AI) and Machine Learning (ML) which are being used for prescriptive rather than preventive maintenance. Prescriptive refractory maintenance is assisted by smart technology where decision making involves massive input data on a real time basis, analytics, machine learning and artificial intelligence. It takes predictive maintenance a step further by implementing an action to solve the issue rather than recommending an action. It helps to reduce the equipment downtime, cost & improve the control & quality of production. Development of the digital twins has completely transformed the way maintenance works are carried out. In this paper, we explain the workings of Artificial intelligence & machine learning. We also focus on how digital twin systems and artificial intelligence are poised to change the way refractory materials are installed and repaired during the maintenance.

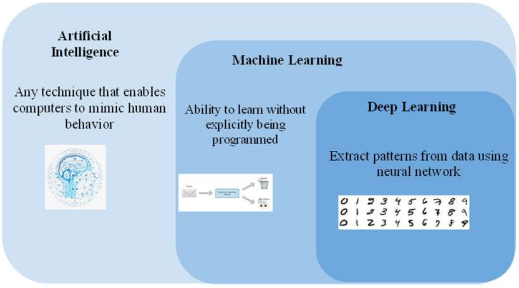
Keywords: Artificial Intelligence; Machine Learning; Big Data; Digital Twins; Prescriptive maintenance; Refractory technology

INTRODUCTION

In the last two and half centuries, the world has witnessed three industrial revolutions. First industrial revolutions started in the 18th century, used water & steam power to mechanize production. The second industrial revolution took place at the end of 19th and at the beginning of 20th century, introduced electrical power which enabled mass production. The invention of transistors in 1947 was the beginning of the third industrial revolution and it used electronics & information technology to automate production [2]. Each revolution has contributed in building the foundation of the previous one and brought advancement in the manufacturing process. It has radically impacted our working environment & daily lives. Now, we are at the cusp of fourth industrial revolutions also known as Industry 4.0.

Industry 4.0 is a developing concept of automation of conventional manufacturing & industrial practices using smart technology such as digital twins, Internet of Things (IOT), Big Data analytics, Cloud computing, advanced robotics, Machine Learning & Artificial Intelligence. Large scale machine-to-machine communication and the internet of things are integrated for increased automation, improved communication and self-monitoring [3].

Introduction to Artificial intelligence & Machine Learning:



How does AI/ML actually work?

Machine learning is part of Artificial intelligence that enables computer systems to think in a similar way to how humans do; learning & improving upon past experience. It works by exploring data, identifying patterns and making predictions. A typical AI/ML model follow the following steps as depicted below fig1:

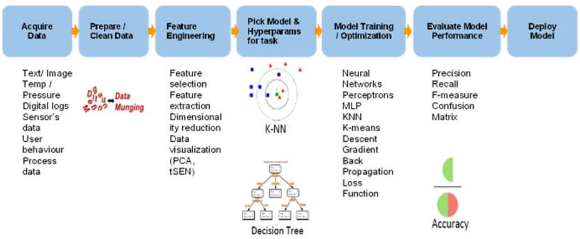


fig 1

Today's AI is denominated by data driven techniques. Our technology infrastructures such as sensors, system logs, user logs, storage availability etc have grown up multi fold leads to availability & accessibility of the data. These data could be an image, sound, text, temperature, pressure, machine RPM, refractory lining thickness, campaign durations, chemical ingredients etc. For example, a smart factory may produce various images of the product components, which are classified as normal or defective. In case of refractory maintenance, input data can be residual thickness of refractory which can be measured using a laser, production parameter such as tapping temperature, processing time, lancing time, blowing time, maintenance data such as amount of mix used during gunning, refractory lining such as type of material used (castable, bricks), lining design & material quality. The next step is to label the data. For instance, images of components from the smart factory can be labelled as 'normal' or 'defective'. Images of refractory lining of teeming ladle can be labelled as 'normal', 'wared out' 'critical' based on the residual thickness. These data are first cleaned and prepared in such a way that it can be used to train machine learning models. According to a survey conducted by Forbes, data scientists spend 80% of their time on data preparation [4] and hence data collection, cleaning & organizing data are critical steps in building up AI/ML projects.

Once, data is collected and organized in a particular fashion, the next step is feature engineering. Feature engineering is the process of using domain knowledge to extract features from the raw data via data mining techniques. It is a very important step in AI/ML which determines the quality of AI/ML outcomes. It drives the AI/ML model performance and governs the ability of the model to generate meaningful insights and ultimately solve the business problem. All the three steps so far discussed are summarized in the below table (fig-2) in form of sample data for better understanding.

Raw Data	
Time	Sample
1	X_1
2	X_2
3	X_3
4	X_4
5	X_5
6	X_6
7	X_7

Rearranged Data				Feature Vector	
Feature-1	Feature-2	Feature-3	Y_i	Feature	Y_i
X_1	X_2	X_3	X_4	V_1	X_4
X_2	X_3	X_4	X_5	V_2	X_5
X_3	X_4	X_5	X_6	V_3	X_6
X_4	X_5	X_6	X_7	V_4	X_7

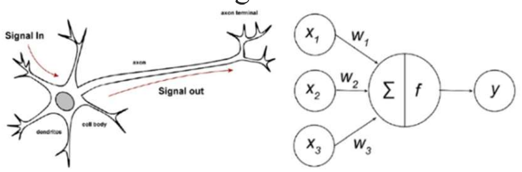
fig-2

In the context of refractory maintenance, refractories properties such as cold crushing strength at various temperatures, apparent porosity, bulk density, refractoriness, hot modulus of rupture, thermal expansion of coefficient, workability, water addition percentage, Alkali resistance and specific process parameters could be the features which have an impact on the refractory wear. The next step is to select the appropriate machine learning algorithms model such as

Linear classification, Support Vector machines (SVM), Artificial Neural Network (ANN), Convolution Neural Network (CNN), logistic regression, K-mean, decision tree, random forest etc where features are used as input data. Once these data get processed through the AI/ML analytical software, it gives output such as a forecast of refractory balance lifetime without maintenance, maintenance proposal including method, schedule, required time etc and holistic understanding of refractory wear mechanism such as impact of blowing time on refractory wear. In order to give a flavour of algorithm, Artificial Neural Network is explained in detail.

Artificial Neural Network (ANN)

The human brain can be described as a biological neural network – an interconnected web of neurons transmitting elaborate patterns of electrical signals. Dendrites receive input signals and based on these inputs, fire an output signal via an axon.[5] One of the key elements of a neural network is the ability to learn, adapt and change its internal structure based on the information flowing through it. Inspired by our biological neural network, an artificial neural network is developed which is basically a mathematical model that uses learning algorithms to store the information [6]. Since neural networks are used in machines, they are collectively called Artificial Neural Networks. Similar to our brain, neural networks are built up of many nods, representing neurons and many connections between them, representing axons and dendrites which carry information. These connections are weighted.



The simplest form of Neural network is perceptron. A perceptron follows the feed-forward model meaning inputs are sent into the neuron which is processed and gives output. The perceptron algorithm calculates the sum of each input multiplied by its weight and passed through activation function and it is represented as $y(x) = f(\sum^{n}_{i=1} W_i X_i)$. Single Neuron with activation function is represented below in fig-3:

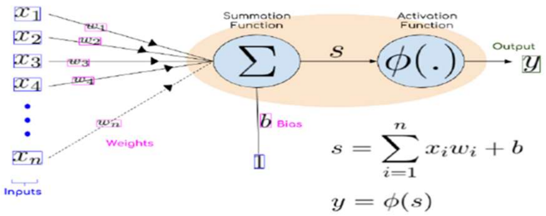
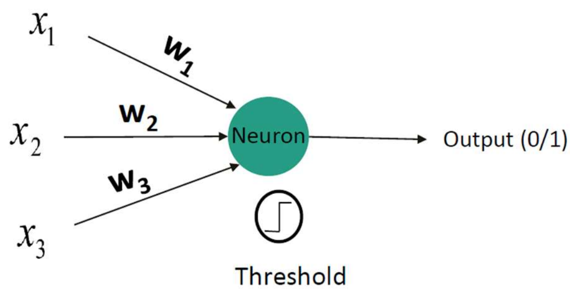
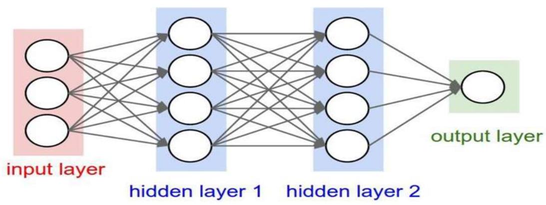


Fig-3

Single Layer Perceptron: One input layer and one output layer of processing units. Single layer perceptron only learn linear functions.



Multilayer Perceptron (Deep Neural Network): For nonlinear functions, multilayer perceptron utilize a non-linear activation function that lets it classify data that is not linearly separable. Multilayer perceptron consists of multiple layers of hidden nodes stacked in between the layer of input & output nodes.



Why multiple layers or hidden layers? As mentioned above, Artificial intelligence is inspired by our human brain where different parts of the brain are responsible for processing different aspects of information and these parts are arranged in hierarchically. As our brain receives inputs & gets processed inside the brain, each level of neurons provides insight and then information gets passed on to the next higher level. This phenomenon is captured in ANN models by hidden layers; as the number of layers increases, the learning capability of the model increases however it also slows down the computer system and hence an optimal number of layers are considered based on the computational power of the system.

The model is required to feed a tremendous amount of information/data to learn and these data are called training sets. During the training period, output of machine algorithms is compared to the human-provided output. If they are the same, the machine algorithm is validated. If it is not, it uses backpropagation (each layer's weights are updated based on the derivative of its output w.r.t input & weight) to adjust its learning which makes a network intelligent. Once, model is trained and optimized, its performance is evaluated in terms of precision, recall, f1-score, mean square error, mean absolute error, R square etc. On successful evaluation, the model can be deployed for its use.

The Evolution of Maintenance

There are five maintenance approaches industry follows for asset management; Reactive, Preventive, Condition Based, Predictive and Prescriptive. Reactive maintenance, also known as corrective maintenance or failure-based maintenance, could be an expensive approach for critical equipment as it may lead to loss of production, opportunity & ultimately customers. Preventive maintenance, also known as time-based maintenance strategy is a proactive approach which could be a reliable approach in such a situation however it might not be effective as there will still be unplanned shutdown & expensive repair that could have been avoided. This type of strategy tends to ensure safety & service maintenance by over-maintaining the asset, thus causing high economic cost. Condition-Based maintenance consists of anticipating a maintenance activity based on evidence of degradation & deviation from the normal behaviour of assets. Condition based monitoring is the first step towards Industry 4.0 maintenance strategy where assets/equipment/machines are continuously monitored and data is being collected either manually or through sensors while they are still running. Predictive maintenance is the advanced version of condition-based approach which forecast the equipment failure in advance and alert the maintenance manager. Predictive maintenance consists of using all the information that composes and surrounds a system, and using it to predict its remaining life. Prescriptive maintenance is the most advanced knowledge-based maintenance strategy which involves the integration of big data (historical & real-time data), analytics, machine learning & artificial intelligence. A prescriptive maintenance system will be a cognitive system where the system will think and perform maintenance just-in-time. The below diagram (fig-4) shows the knowledge & information that need to be collected to obtain intelligent maintenance [7].

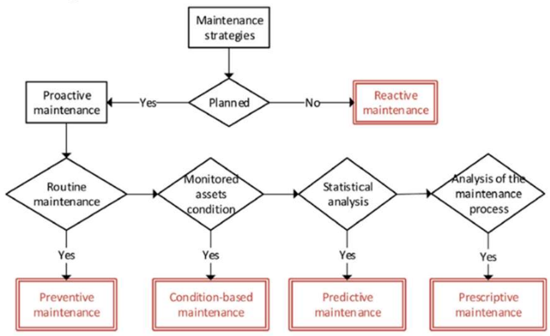


Fig-4

Digital Twins

Digital twins is a virtual representation of a physical object, asset, processes, system or device across its life-cycle. It uses real-time data and other sources to enable learning, reasoning and dynamically recalibrating for improved decision making [8]. Digital twins integrate Internet of things, artificial intelligence, machine learning and software analytics with spatial network graphs to create living digital simulation models that update and change as their physical counterparts change. A digital twin continuously learns and updates itself from multiple sources to represent its real-time status, working condition or position.

How does Digital Twins Work?

Digital twins were developed by NASA to operate, maintain or repair systems when they are not within physical proximity to the system. Let's think of Digital Twins as a bridge between the digital and physical world. Thousands of sensors distributed throughout the physical assets collectively capture data along a wide array of dimensions from behavioural characteristics of equipment, work in progress such as thickness, temperature, basicity, velocity, Alkalies etc and environmental conditions within the plant. These data are continuously communicated to and aggregated by the Digital Twin system. The digital twin application continuously analyses incoming data streams and compares it with an ideal range of acceptable data. Investigation and corrective action get triggered when the system detects trends outside the acceptable range [9].

The Refractory Maintenance

Refractories are designed to withstand harsh operating temperatures and act as a protective layer for the process vessel. It plays a significant role in high temperature industrial vessels, such as, metallurgical vessels for Iron & Steel making, rotary kiln for cement industry & many other vessels for foundry, Aluminium industries. The vessels are subjected to a severe operating environment during service & their performance influenced the operating process. The campaign life of refractory depends upon thermal and thermomechanical behaviour [10]. Heavy dust, temperature often higher than 1600 deg C and multiple simultaneous corrosion mechanisms limit the possibility of exact measurements and thus the predictability of refractory lifetime. In such situations, equipment operators depend heavily on the operator's experience to determine when the refractory linings are due for maintenance. This, combined with significant variability that is inherent in the process, can often lead to suboptimal performance and inconsistent results contribute to either shorter campaign life or failure of refractory. Use of industry 4.0 not only eliminates this deficiency but also improves overall equipment/plant performance along with safety and wellbeing of people involved in maintenance. Equipment, process, operating parameters & maintenance practice are major drivers of refractory product selection which is predominately made by humans on the basis of knowledge and experience. This may change in the future as artificial intelligence develops further where the decision process will be increasingly assisted by self-optimizing and knowledgeable manufacturing systems. The smart factory will be equipped with a digital twin and cyber-physical system which will enable the communication between humans, machines and products alike. As they are able to acquire and process the data, they can self-control certain parts and interact with humans via interface [11].

In Iron making, blast furnace (BF) is the major equipment which requires significant refractory maintenance on a daily basis to operate it smoothly & efficiently. Although blast furnaces have been in operation since many centuries, it is still a grey area for operations & maintenance teams when it comes to inner refractories lining systems. It is nearly impossible to predict the wear & tear of inner refractory lining without shutting the furnace[12]. In such a situation, a digital twin of blast furnace can continuously monitor the Blast furnace's refractory lining which will not only help operators to maximize the refractory campaign life but also make the process 100% safe to operate. An intelligent maintenance concept can help to improve refractory efficiency which results in higher service life, higher hot metal production and more flexibility for plant maintenance at reasonable refractory costs.

In steel making, digital twins of refractory lining of basic oxygen furnaces (BOF) can be generated to predict the refractory lifetime which will help operators to operate the BOF at optimized production level with increased safety. The laser measurement system will measure the refractory lining thickness after certain frequency (initially, it could be at every 10 heats and later every alternate heats) and send the data to Digital twins system where refractory wear model will automatically generated with the help of machine learning without any human intervention and will provide real-time wear lining pattern & balance life. This is further integrated with the gunning equipment which can automatically trigger as per the situation to repair the refractory lining.

Conclusion

Uses of smart & intelligent technology are transforming traditional maintenance practice into smart maintenance practice AI/ML and digital twins are enabling this paradigm shift which address some of key challenges such as unforeseen downtime for relining, suboptimal and excessive maintenance practices, unsafe operations etc. The new smart technology helps to create refractory wear models, precisely identify the key wear influencing parameters, do the refractory benchmarking and automate the maintenance. This helps plant operators to predict the lifetime of lining, reduce refractory consumption and increase safety. In nutshell, AI/ML, digital twins, IIOT etc are the backbone of industry 4.0. The deployment of cutting-edge AI and machine learning technology along with digital twins will lead to massive disruption in the refractory lining maintenance.

References

[1] Reinhold Steiner, Gregor Lammer, Christian Spiel, and Christoph Jandl, "Refractories 4.0" , BHM (2017) Vol. 162 (11): 514–520.
[2] Industries 4.0 Working Group: Recommendations for implementing the strategic initiative Industries 4.0, 2013.
[3] Wikipedia: https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution.
[4] Forbes 2016: Data Science Task Survey.
[5] Daniel Shiffman, "Nature of Code", Chapter 10, Neural Networks.
[6] Steven Walczak, Narciso Cerpa, in Encyclopedia of Physical Science and Technology (Third Edition), 2003.
[7] The Digital Mine: A Four-step Approach to Predictive Maintenance 4.0.
[8] IBM Blog - Digital Twins in Nutshell
[9] Digital Twin for maintenance: A literature review by Itxaro Errandonea, Sergio Beltran, Saioa Arrizabalaga.
[10] Application of Some digital Techniques to optimize the Thermomechanical behaviour of refractory lining, Aidong Hou, Montan Universitat Leoben.
[11] Medium ARTICLE - Uses of Artificial Intelligence in Refractory Maintenance, Prakash Bharati.
[12] LINKEDIN ARTICLE - Uses of Artificial Intelligence in refractory maintenance, Prakash Bharati.

Refractory Raw Materials: Problems and Prospects

S. Sinhamahapatra, V. P. Reddy, S. Pasari, K. Dana, H. S. Tripathi
CSIR-Central Glass & Ceramic Research Institute
Kolkata 700 032, India
[a] Corresponding author's email: somnaths@cgcri.res.in

Abstract

India is endowed with large reserve of major refractory raw materials namely magnesite, sillimanite and bauxite. However, refractory grade good quality bauxite is nearly exhausted in India and existing Indian bauxite contains impurities such as SiO_2, Fe_2O_3, TiO_2, and CaO. These impurities can form low melting phases such as iron aluminum titanate ($FeAlTiO_5$) along with the vitreous phases at high temperatures, which restrict their use for refractory applications at high temperatures. On the other hand, Indian magnesite is associated with CaO, Fe_2O_3 and SiO_2 and these impurities may form low melting phase merwinite [$Ca_3Mg(SiO_4)_2$] and monticellite ($CaMgSiO_4$). Additionally, the impurity content also varies with location. Therefore, a single strategy of beneficiation will not be useful for all the materials and this warrants a multipronged approach to solve this problem. In this paper, the problem associated with the Indian raw materials and their up-gradation is explained.

Keywords – Bauxite; Sillimanite; Magnesite; Refractory; Mullite

INTRODUCTION

Refractories are the backbone of high temperature process industries like steel, cement, copper, aluminium, glass and ceramic. The process parameters and the operating environment in these industries differ significantly, which requires different type of refractory for different applications. Consequently, different refractory raw materials are in demand both synthetic and natural. Among all these, alumino-silicate and magnesite based refractory constitute the major portion of all the refractory materials. As a result, bauxite and magnesite are having high demand as refractory raw materials and this will further increase with the increase in steel production. As India is targeting to achieve a steel production capacity of 300 million ton per annum, the importance and demand of these refractories will increase by many folds. At the same time demand for quality refractory is also continuously increasing. The quality of the starting raw materials dictates the quality of the refractory products. Though India has large reserve of bauxite and magnesite, however the associated impurities, which may form low melting phases at high temperatures, restrict their use for refractory manufacturing. CSIR-Central Glass & Ceramic Research Institute (CSIR-CGCRI) has been consistently working on Indian refractory raw materials especially bauxite and magnesite for the value addition. In this paper, attempt is made to focus on the CSIR-CGCRI activities on bauxite, sillimanite beach sand and magnesite of Indian origin for their value addition.

BAUXITE

Bauxite is the primary raw material used for the production of high alumina refractory. Calcined bauxite is also used as refractory aggregate. Bauxite is available in nature in different hydrated hydrate forms of alumina such as gibbsite ($Al_2O_3.3H_2O$; Al_2O_3: 65.4%), diaspore and boehmite ($Al_2O_3.H_2O$; Al_2O_3: 85%). The estimated total bauxite reserves in the world are 30 billion tonnes. Guinea has highest bauxite reserves (25%) in the world. Other major sources are located in Australia

(17%), Vietnam (12%), Brazil (9%), Jamaica (7%), Indonesia (4%), China (3%) and Russia (2%). The world total bauxite production in the year 2019 is 347 million tonnes and Australia is the major producer (30%) of bauxite in the world [1]. Country wise world reserve of bauxite is shown in Table I.

Table I: World reserve of bauxite[1]

Country	Reserve (,000 tonnes)	Reserve* %
Australia	5100000	17
Brazil	2700000	9
China	1000000	3
Guinea	7400000	25
India	660000	2
Indonesia	1200000	4
Jamaica	2000000	7
Kazakhstan	160000	1
Malaysia	170000	1
Russia	500000	2
Saudi Arabia	190000	1
United States	20000	0
Vietnam	3700000	12
Other countries	4900000	16

** rounded off to nearest whole number*

India has around 656 million tonnes reserves and 3,240 million tonnes of resources of bauxite as on 1.4.2015. However, out of the reserves, 77% is of metallurgical grade and only 4% can be used as refractory or chemical grade. Indian bauxite mostly contains SiO_2, TiO_2, and Fe_2O_3 as impurity materials and some of the sources also contain CaO as impurity. These impurities restrict the use of bauxite in the refractory for high temperature applications. Typical compositions of two different types of Indian bauxite are shown in Table II.

Several up-gradation techniques such as chemical and bio-leaching, magnetic separation, flotation process have been adopted to minimise the impurities from bauxite. CSIR-CGCRI has employed a different strategy to upgrade the impure Indian bauxite without or with minor beneficiation [2-4].

Table II: Typical chemical composition of Indian bauxite

Constituent, wt%	Type1	Type 2
SiO_2	3-6	5-10
Al_2O_3	51-55	51-55
Fe_2O_3	5-8	2-5
TiO_2	5-8	2-5
CaO	0.1-0.3	2-4
LOI	23-25	25-27
RUL, ta, °C	1440-60	1440-50

Mullite is a solid solution of alumina and silica, which can accommodate different cations in its structure up to a certain extent. CSIR-CGCRI has utilised this concept and developed high alumina (mullite) aggregates from impure Indian bauxite by adding clay, other silica containing materials and sintering additives. The main aim was to achieve the mullite formation at a temperature lower than that of other low melting compound formed from impurities (e.g. $FeAlTiO_5$). In this process, the phase assemblage was modified by converting the impurities into high melting phases. It was also possible to achieve improved properties of the bauxite where CaO is present in minor amount. The properties achieved are shown in Table III.

Table III: Properties of refractory aggregates developed from bauxite of Indian origin (unprocessed and processed) and imported bauxite

Properties	Indian bauxite	Indian bauxite (processed)	Imported bauxite
B.D. (g/cc)	2.90	2.80	3.06
A.P. (%)	12.4	10.1	13.9
RUL, t_a°C	1450	1600-1630	1610

The mullite aggregates sintered at 1600 °C showed compact microstructure with very small amount of glassy phase whereas the microstructure of bauxite contains low melting phases in the microstructure. The bauxite, which contains significant CaO, was partially beneficiated by dilute organic acid leaching process and converted to refractory products by mullite formation using a particular silica source. And it was possible to achieve improved properties with this bauxite.

SILLIMANITE BEACH SAND

Alumina- based refractories are ubiquitous in several high temperature structural materials. It is produced from natural minerals like bauxites, sillimanite group minerals and clays. Currently world is moving towards producing cleaner steel with minimum refractory consumption and increased life, which obviates the use of synthetic and purer raw materials for producing refractory products. Depletion of pure minerals and lack of indigenous resources have forced Indian refractory manufacturers to depend upon imported raw materials. The uncertainty in steady supply and price escalation of these imported raw materials can only be managed if high quality synthetic refractory aggregates are manufactured in India. India has very long coast line of 7600 km and huge deposit of beach sand minerals. Sillimanite beach sand is generated as by product during rare earth extraction process from beach sand and is partly used for miscellaneous purposes like abrasive, ceramics. This sand is a pure form of alumino silicate with very low amount of impurities. It can be value added to form synthetic aggregate and subsequently useful refractory. Typical chemical composition of Indian beach sand sillimanite from two different regions is shown in Table IV.

At CSIR-CGCRI, sillimanite beach sand was converted to mullite ($3Al_2O_3.2SiO_2$) by adjusting the stoichiometry of Al_2O_3:SiO_2 using calcined alumina. Sintering additive and its amount was optimized in terms of its effect on on densification and flexural strength of the developed aggregates.

Table IV: Typical Chemical composition of sillimanite beach sand from two different locations

Chemical constituents (%)	Quilon	OSCOM
SiO_2	37.1	38.0
Al_2O_3	59.3	56.6
Fe_2O_3	0.5	0.4
TiO_2	0.4	0.25
CaO	0.6	0.4
MgO	-	0.31
ZrO_2	1.5	-

High alumina refractory aggregates having Al_2O_3:SiO_2 =3:2 was prepared by two different techniques i.e. roll briquetting and granulation.

Fig. 1: Sintered high alumina aggregates (briquettes) prepared from sillimanite beach sand.

Sintered aggregates were prepared using calcined alumina and sintering additives through reaction sintering route. These aggregates were characterized in terms of apparent porosity (A.P.), bulk density (B.D.) and specific gravity. The formation of mullite phase in the sintered aggregates (Fig. 1) was confirmed by specific gravity value. The properties of the sintered aggregates prepared from sillimanite are shown in Table V.

Table V: Properties of sintered aggregates developed in two different techniques

Properties	Nodules	Briquettes
A.P. (%)	1.6	0.74
B.D. (g/cc)	2.81	3.04
Specific gravity	3.13	3.13

Properties of these aggregates were benchmarked with the commercially available aggregates (Table VI) in terms of chemical composition, densification behaviour and pyrometric cone equivalent. Developed aggregates were found to be comparable with the commercially available aggregates.

Table VI. Comparative evaluation Properties of aggregates developed from beach sand sillimanite

Properties	Commercial aggregate	Developed aggregates
Constituents (wt%)		
Al_2O_3	68.0 Min	69.4
SiO_2	28.0	28.2
Fe_2O_3	1.5 Max	0.47
A.P. (%)	4.0	1.0 -1.50
B.D. (g/cc)	2.80 (min)	2.8-3.0
PCE (Orton cone)	39	36+ (1804°C)

Prototype shaped refractory (standard size brick; 9″x4.5″x3″) bricks were prepared in the laboratory using the developed aggregates after crushing and grinding. Granulometry of the aggregates was adjusted to achieve proper densification in case of shaped refractory. Developed prototypes were fired at 1600°C and the standard refractory properties were evaluated. The properties are given in Table VII.

Table VII: **Comparative evaluation of properties of standard refractory bricks**

Properties	Standard refractory brick	Developed brick
A.P. (%)	20	19.9
B.D. (g/cc)	2.5	2.51
CCS (kg/cm^2)	500	462
Hot MOR at 1400°C (kg/cm^2)	-	52
RUL (°C)	1700	> 1640

MAGNESITE

Magnesia is the most important basic refractory, which is ubiquitous in the steel making process. It is also prevalent in the cement industries. The essential raw material for magnesia containing refractory is magnesite ($MgCO_3$), which is a naturally occurring minerals. It is available in the countries like China, Korea, Greece, Austria, Australia, Brazil, Turkey etc. Alternatively, magnesia is produced from seawater, lake bitterns, and in-land brine through chemical process. This mineral is used mainly as refractory in the form of dead burnt and fused materials for producing MgO-C, Mag-chrome, Mag-aluminate spinel and fired magnesite brick. Dead burning of magnesite is done around 1800°C to make the magnesia stable. The total reserve of magnesite in the world 7,600 million tonnes [5]. Russia has highest reserve of magnesite (30%). The percentage of magnesite reserve is shown in Fig. 2. However, China is the major producer of magnesite (64%) which is followed by Russia, Turkey and Brazil.

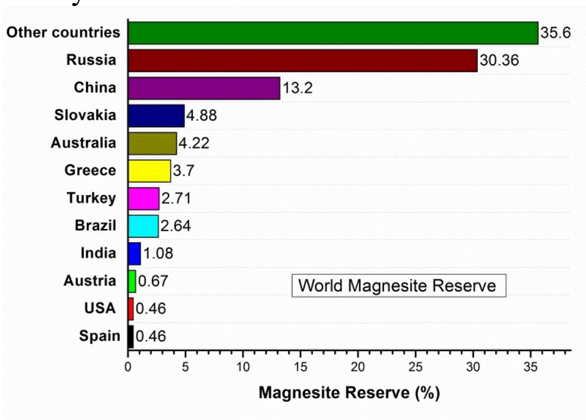


Fig. 3: World magnesite reserve[5]

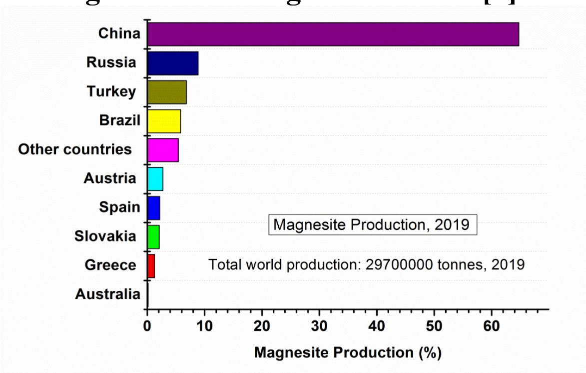


Fig. 4: World magnesite production[5]

Indian magnesite reserve is 82 million tonnes and resource is 312 million tonnes. Major magnesite resources are available in the state of Uttarakhand, Tamil Nadu and Rajasthan. Andhra Pradesh, Jammu, Himachal Pradesh, Karnataka and Kerala also have magnesite resources. The major impurities that can be associated with magnesite are CaO and SiO_2 along with Fe_2O_3 and Al_2O_3.

Table VIII: Typical Composition of Indian magnesite

Constituents (%)	Magnesite source	
	Salem	Almora
MgO	88-90	82-84
CaO	2-7	5 (max)
SiO_2	4-8	4.5 (max)
Fe_2O_3	Tr.	4-6

Indian magnesite of Salem region of Tamil Nadu contains high amount of SiO_2 as impurities whereas Almora magnesite is associated with CaO and Fe_2O_3. These impurities can form low melting phases such as monticellite (CMS), merwinite (C_3MS_2) and di-calcium ferrite. Formation of these low melting phases restricts the use of Indian magnesite for high temperature refractory applications. Several attempts have been made by different researchers for the up-gradation and utilisation of Indian magnesite through different routes for high temperature applications such as separation of the impurities, effect of additives to control the low melting phase formation etc. [6-10]. CSIR-CGCRI has taken multidirectional approach for the proper utilisation of Indian magnesite. Sintering behaviour and other high temperature properties and the microstructure of both Salem and Almora magnesite was extensively studied. Effect of additives such as TiO_2, ZrO_2,Y_2O_3 on the densification and properties of Indian magnesite was studied to explore the possibilities of utilisation of Indian magnesite for refractory applications [8, 10-12]. The basic objective of the additive is the suppression of the low melting phase formation by forming a high temperature phase. In addition to this, ZrO_2 utilises the CaO present in magnesite for its phase stabilisation and thereby reduces the availability of CaO in the system [8]. Another approach is tailoring the lime/silica ratio to control the phase formation of Indian magnesite. Lime/silica ratio plays a pivotal role in the phase formation of magnesite. Lime/silica (C/S) ratio of <1.5 promotes the low melting monticellite (CMS) and (C_3MS_2) formation whereas higher C/S ration of >2 prefers the formation of high melting C_2S and C_3S phases. Improvement in high temperature properties of Salem magnesite was reported by judicial adjustment of the lime silica ratio. Lime/silica ratio of 2:1 is reported to be beneficial in terms of thermo-mechanical properties due to the reduction of CMS phase [13]. Another approach employed by CSIR-CGCRI is converting this magnesite to magnesium aluminate spinel through reaction sintering process [10, 14]. Unlike to alumina based refractories, which has whole gamut of applications for different alumina content, application of magnesia requires high MgO content. This makes the removal of the impurities an utmost necessary for the applications of Indian magnesite for high temperature applications. Reverse flotation technique was used to separate the silica from

Salem magnesite and the reduction of quartz content from 2.3 % to 1.8% was achieved [15]. In an another approach, electric arc plasma melting of impure magnesite in presence of additives in electric arc furnace was carried out so that the pure magnesia phase can be separated from the impurities through gravity separation. Also it was aimed at producing large magnesia crystals. The coke could reduce the impurities present in magnesite (Fe_2O_3 and SiO_2) into metallic form and convert them into ferrosilicon (Fe-Si) metals. Due to high density, the ferrosilicon metals would separate from magnesia melt through density separation. In the preliminary work carried out at CSIR-CGCRI, purification of magnesite from 84.5% MgO to 91.81% MgO was achieved through arc melting as assessed through XRF, EDS and chemical method.

CONCLUSION

Improvement in high temperature properties of Indian bauxite and magnesite was achieved through different value addition process. However, some of these processes have their inherent limitations. A multipronged approach involving beneficiation, arc melting and phase modification is extremely essential for improvement of these raw materials for self-reliance.

ACKNOWLEDGEMENTS

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REFERENCES

[1] "Indian Minerals Yearbook 2020 (Part-III : Mineral Reviews) : Bauxite," 59 ed: Indian Bureau of Mines, Ministry of Mines, Government of India, 2022.

[2] A. V. Maldhure, H. S. Tripathi, and A. Ghosh, "Mechanical properties of mullite-corundum composites prepared from bauxite," *Int. J. Appl. Ceram. Technol.,* vol. 12 pp. 860-866, 2015.

[3] A. V. Maldhure, H. S. Tripathi, A. Ghosh, and S. K. Das, "Mullite-corundum composites from bauxite: Effect of chemical composition," *Trans. Ind. Ceram. Soc.,* vol. 73, pp. 31-36, 2014.

[4] H. S. Tripathi, A. Ghosh, M. K. Halder, B. Mukherjee, and H. S. Maiti, "Microstructure and properties of sintered mullite developed from Indian bauxite," *Bull. Mater. Sci.,* vol. 35, pp. 639-643., 2012.

[5] "Indian Minerals Yearbook 2020 (Part-III : Mineral Reviews) : Magnesite," 59 ed: Indian Bureau of Mines, Ministry of Mines, Government of India, 2022.

[6] A. K. Mishra, P. Roy, S. S. R. Mahapatra, B. Mohanty, and S. Majumdar, "Bioleaching of silica from magnesite ore," *Indian J. Technol.,* vol. 24 p. 770, 1986.

[7] B. K. Mohanty and A. K. Mishra, "Physical and chemical factors affecting the release of silicafrom magnesite ore by a Bacillus Sp.," *J. Gen. Appl. Microbiol.,* pp. 233-241, 1988.

[8] Burhanuddin, A. Kumar, P. Kumar, A. Ghosh, S. Sinhamahapatra, and H. S. Tripath, "Effect of zirconia on densification and properties of natural Indian magnesite," *Int. J. Miner. Process.,* vol. 144, pp. 40-45, 2015.

[9] B. D. Chattaraj and M. K. Chatterjee, "Beneficiation of Magnesite-An Alternate Approach," *Trans. Ind. Ceram. Soc.,* vol. 38, pp. 188-196, 1979.

[10] C. Ghosh, A. Ghosh, and M. K. Haldar, "Studies on densification, mechanical, micro-structural and structure–properties relationship of magnesium aluminate spinel refractory aggregates prepared from Indian

magnesite," *Mater. Charact.,* vol. 99, pp. 84-91, January 2015.

[11] P. Kumar, A. Ghosh, and H. S. Tripathi, "Study of densification behaviour, microstructure vis-à-vis high temperature properties of commercially available Indian magnesites," *Trans. Ind. Ceram. Soc.,* vol. 75 pp. 250-255, 2016.

[12] P. Kumar, M. Nath, U. Roy, A. Ghosh, and H. S. Tripathi, "Improvement in thermomechanical properties of off-grade natural magnesite by addition of Y_2O_3," *Int. J. App. Ceram. Technol.,* vol. 14 pp. 1197-1205, 2017.

[13] C. Ghosh, A. Ghosh, H. S. Tripathi, J. Ghosh, and M. K. Haldar, "Studies on densification, mechanical, microstructural and structure-properties relationship of refractory aggregates prepared from Indian magnesite by changing lime-silica ratio," *Ceram. Int.,* vol. 40, pp. 16791-16798, 2014.

[14] S. Sinhamahapatra, H. S. Tripathi, and A. Ghosh, "Densification and properties of magnesiarich magnesium-aluminate spinel derived from natural and synthetic raw materials," *Ceram. Int.,* vol. 42, pp. 5148-5152, 2016.

[15] C. Ghosh, S. Sinhamahapatra, H. S. Tripathi, and U. Sarkar, "Reverse Flotation of Natural Magnesite and Process Optimization Using Response Surface Methodology," *Trans. Ind. Ceram. Soc.,* vol. 79, pp. 1-7, 2020.

Innovative solutions and tredns of high alumina refractories for modern iron and steel applications

Shankha Chatterjee, Almatis Alumina Pvt. Ltd. India.
Andreas Buhr, Almatis GmbH.

Abstract

The continual development of steel producing technology is a main driver for the development of new high alumina refractories. The paper briefly discusses the trends in steel secondary metallurgy and how modern alumina refractories provide innovative solutions for challenging conditions in the steel making process. Examples are given how refractories contribute to steel quality and economical improvements in the process.

Introduction

When considering trends in high alumina refractories, trends in the steelmaking technology have a major influence. The steel industry consumes between 60 and 70% of the refractories, and taking into account synthetic alumina based aggregates such as tabular alumina, the share of consumption in the steel industry is even higher at around 80%. Therefore relevant trends in steel technology shall be briefly discussed first, because they are main drivers for developments in alumina refractories. In the second part of the paper, specific developments and innovations especially in high purity alumina refractories will be presented.

Trends in secondary metallurgy

Trends in the steel making technology have been discussed in detail by Fandrich et al. [1] and Bruckhausen and Fandrich [2]. With regard to the focus of this paper, they can be briefly summarised as follows.

There is continuous development of new steel grades with tailored properties for various, very different applications. These are high purity steel grades with tight specifications for undesired impurities and alloying elements. **Fig. 1** shows the achievable content of impurities in steel over the past 50 years. The improvement of steel is to a great extend achieved by treatment in the steel ladle. The strong impact of this so-called secondary metallurgical treatment in the steel ladle from 1980 onwards is obvious. Analyses of typical steel grades for automobiles in **fig. 2** demonstrate the increasing demand for low impurities and specification of steel.

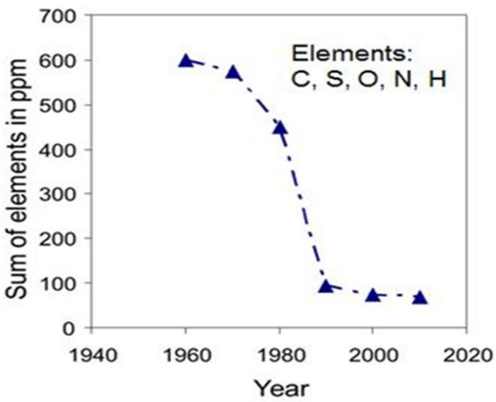


Fig. 1 Achievable contents after secondary metallurgical treatment between 1960 and 2010 [1]

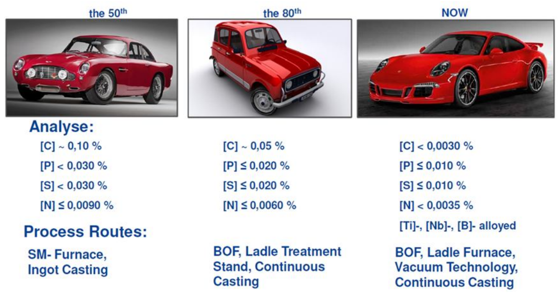


Fig. 2 Metallurgical challenges – example automobile industry [3]

Secondary metallurgy covers a broad range of processing such as de-oxidising, de-gassing, de-sulphurisation, de-carburisation to ultra-low carbon contents, alloying in tight specification ranges, improvement of steel cleanliness by separation or modification of non-metallic inclusions, and last not least homogenisation of composition and temperature. Lachmund [4] therefore refers to the steel ladle as a "metallurgical reactor" (**Fig. 3**).

The steel is constantly cooling down during the extended treatment times in the steel ladle. Therefore either higher tapping temperatures from BOF or EAF or re-heating of the steel in a ladle furnace or with thermo-chemical methods such as CAS-OB are required to compensate this temperature loss and ensure the right temperature for the casting of steel.

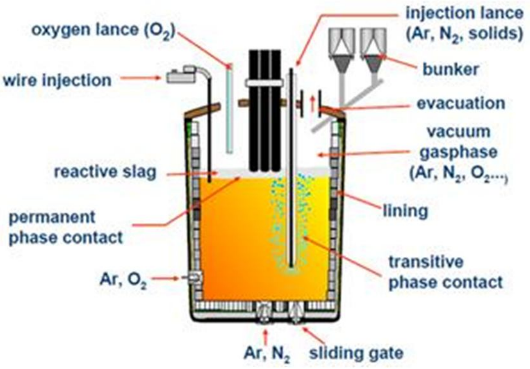


Fig. 3 The steel ladle as a "metallurgical reactor" [4]

The high number of different steel grades (>2000) but also the different conditions in each steel plant, where none is exactly like another, require multiple and complex processing routes during secondary metallurgy in order to finally achieve the desired high quality steel product. Careful and exact planning and performance of processing is needed for technical and economical successful steel production. Bruckhaus [2] therefore reported about "zero error strategies" with maximum productivity and flexibility as an important trend in modern steel making.

Secondary metallurgy can only be performed with high performance refractory linings in the steel ladle. The following examples demonstrate how modern high purity alumina refractories in steel ladle lining provide technical and economical solutions for challenging conditions in modern steel making.

Developments in high alumina refractories

Refractories for steel ladle side walls must withstand slag attack by aggressive, metallurgical reactive slag e.g. calcium-aluminate slag with CaO/Al_2O_3 ratio around 1 for Al-killed steel. In addition, the refractory lining must be thermodynamically stable in contact with steel, e.g. excess dissolved aluminium in Al-killed steel, in order to avoid re-oxidation of the steel and problems with the steel cleanliness.

Silica containing high alumina refractories such as andalusite or bauxite show high wear-rates with aggressive, low melting calcium aluminate slag. The SiO_2 in these refractories is thermodynamically not stable in contact with aluminium in the liquid steel and is reduced by the aluminium forming Al_2O_3, which degrades the steel cleanliness. Therefore high purity alumina-spinel refractories have replaced andalusite and bauxite in ladle linings.

Alumina-spinel refractories are successfully used in ladle side walls for both, Al- and Si-killed steel grades. They are applied either as castables or bricks. In steel ladle side walls, spinel forming castables provide advantages when compared with spinel containing castables due to slag resistance and thermoplastic behaviour at elevated temperature [5]. Bricks are either high-fired carbon free bricks or carbon bonded spinel forming AluMagCarbon (AMC) bricks.

Such fired spinel bricks must have very low SiO_2 contents in order to provide the desired performance. Franken et al. [6] reported that spinel bricks with 1% SiO_2 achieved only 40% of lifetime when compared to spinel bricks with 0.1% SiO_2. Consequently, classical clay binder concepts for fired bricks must be modified e.g. by use of reactive alumina.

The performance of AMC bricks depends on the alumina aggregate used. Bauxite containing bricks represent the lowest quality. Such bricks cannot provide the performance reserve necessary for more demanding and flexible processing of steel in the ladle. In the ladle bottom, high purity AMC bricks based on tabular alumina clearly outperform brown fused alumina bricks. Krausz et al. [7] reported about a 50% lifetime reduction with brown fused alumina instead of tabular alumina in ladle bottom bricks. The high purity tabular bricks provide higher creep and slag resistance and the most consistent rate of spinel formation during thermal cycling.

Alumina based carbon free refractories provide two important advantages for the ladle side wall when compared to MgO/C bricks with carbon contents of 10% or higher. They avoid a carbon pick up of ultra-low carbon steels from the refractory lining and have lower thermal conductivity, for example 3.5 vs. around 10W/mK.

The carbon pick up of steel from the refractory lining depends on the overall carbon content and the presence of graphite in the refractories. Laboratory investigations at Dillinger Hütte [8] showed that carbon pick up from doloma bricks, which do not contain graphite, is only high for the first use but much lower afterwards. For graphite containing refractories such as continuous casting materials (25% C) or MgO/C bricks (10-15% C) the carbon pick up remains high for subsequent use as well (**Fig. 4**).

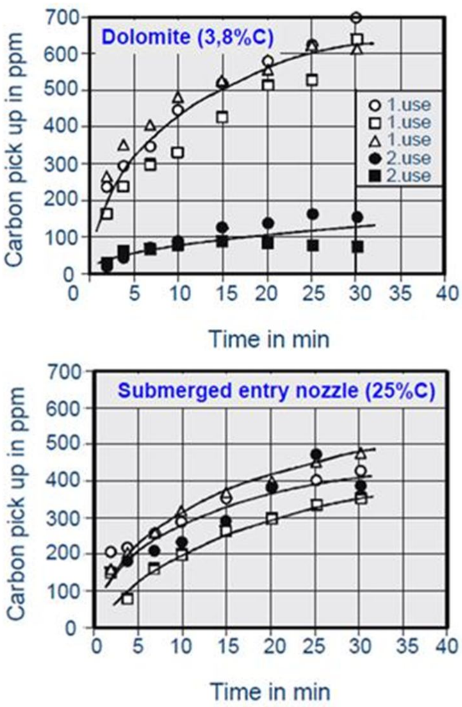


Fig. 4 Carbon pick up of steel from refractories in submersion laboratory testing: low vs. high carbon refractories [8]

Fig. 5 shows the temperature loss in a 180 ton steel ladle with spinel forming castable in comparison to MgO/C bricks in the ladle side wall. The temperature loss with MgO/C is 10-15 K higher in spite of an additional insulation layer in the permanent lining. Such higher temperature losses account for higher steel manufacturing cost in the range of 0.3-0.5 Euro/ton of steel due to higher tapping temperatures or additional re-heating of the steel in the ladle furnace.

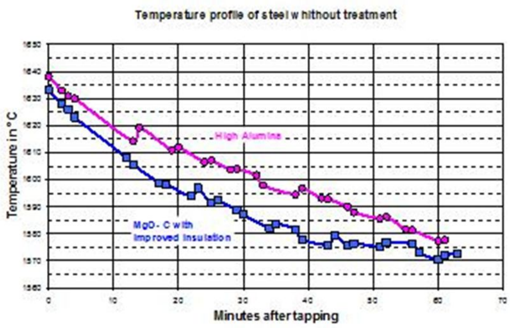


Fig. 5 Steel temperature development in a 180 tonnes steel ladle with different lining concepts: alumina monolithic vs. MgO/C bricks [9]

Fired spinel bricks for steel ladle side wall lining provide an alternative to spinel castables when a steelwork doesn´t want to do the technology change from bricked to monolithic linings. Low specific refractory consumption in the range of 0.5kg/ton steel for the wear lining in the steel ladle side wall are achieved with both concepts. However, for the slag line most often MgO/C bricks are used.

Another example for innovative alumina refractories are calcium hexa-aluminate (CA_6) materials which provide a combination of safety and reduced thermal losses for the permanent linings in steel ladles. Schnabel et al. [10] reported about the high slag resistance against calcium aluminate slag (**Fig. 6**) and the low thermal conductivity (**Fig. 7**) of dense CA_6 material bonite, which makes it an interesting solution for steel ladle safety lining.

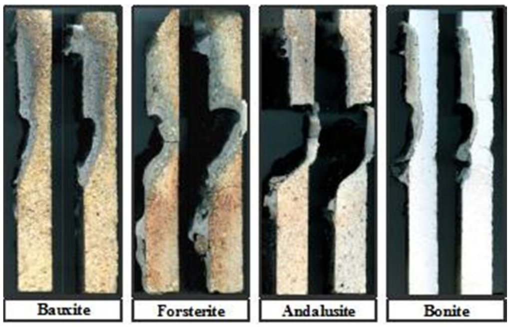


Fig. 6 Samples after slag test; CaO/Al_2O_3-ratio 1.08, (Induction furnace, 1600 °C / 2 h; air) [10]

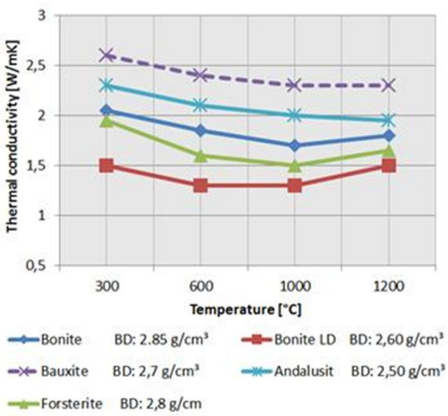


Fig. 7 Thermal conductivity of steel ladle permanent lining materials [10]

The challenges on ladle permanent linings are increasing because the lining thickness of both, wear and permanent lining is reduced in order to increase the steel capacity of the ladle. A reduction of 10 mm lining thickness increases the steel capacity of a 200 tons ladle by 2.5 tons. Simultaneously, heat losses shall be reduced as already discussed above. Therefore insulating layers have become a standard in European steel ladle lining. These insulating layers must be protected from over-heating because their application temperature limit is only around 1000°C. A safety lining with low thermal conductivity such as bonite in front of the insulating layer can make an additional layer by an insulating brick obsolete (**Fig. 8**) and thus strengthen the whole mechanical stability of the permanent lining.

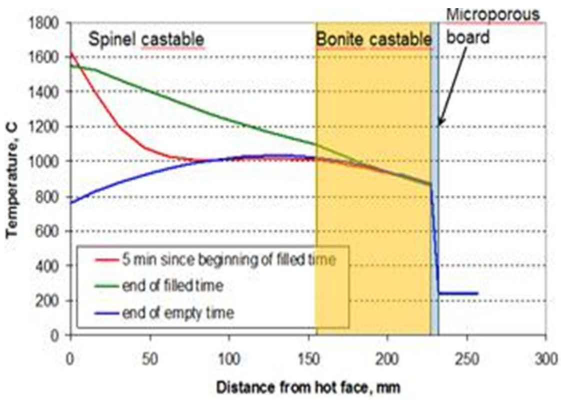
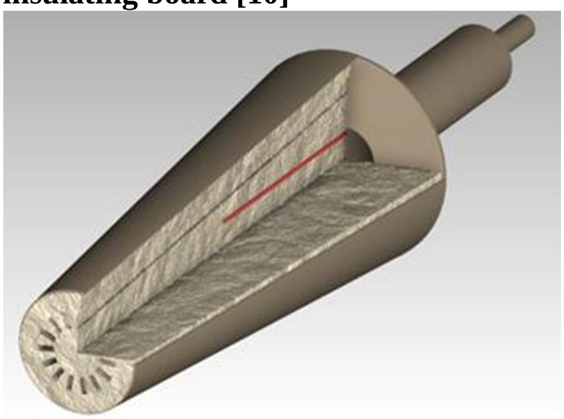


Fig. 8 Thermal modelling of steel ladle lining: 155mm spinel castable – 72mm Bonite castable – 5mm micro-porous insulating board [10]



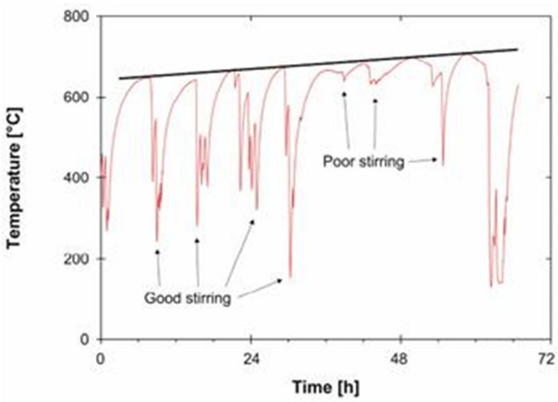


Fig. 9 Temperature changes in a steel ladle purging plug during ladle cycling and stirring [11]

Pre-cast shapes such as purging plugs and well blocks in the steel ladle bottom are an essential part of the ladle lining concept. The metallurgical treatment cannot be performed without stirring the steel in the ladle. Flow rates range from 100Nl/min up to 1500Nl/min per purging plug. Soft bubbling is applied for transferring oxide inclusions to the top slag and increasing the steel cleanliness. Stronger stirring is required for alloying and homogenisation, and especially for vacuum treatment in tank degassing.

The plugs can be exchangeable during hot cycling of the ladle but the well blocks can often be the bottleneck for achieving the desired campaign length of the whole ladle. Therefore highest quality tabular alumina-spinel materials have become the standard for this application. The water demand of the castables is reduced to 3-4 % by using reactive alumina and high performance additives such as dispersing aluminas ADS/W in the matrix fines. In order to achieve the required hot strength and erosion resistance, silica fume must not be used here as is discussed in detail by Schnabel et al. [5]. High purity spinel containing materials have hot modulus of rupture (HMoR) at 1500°C of 30MPa, refractoriness under load (RUL) T05 > 1700°C, and creep rates at 1600°C of 0.01-0.02%/h, both at 0.2MPa load.

Purging plugs are exposed to severe thermal shock conditions as shown in **fig. 9**. A thermocouple was placed in the purging plug as indicator for the stirring performance [11]. When the purging plug is clogged and no stirring gas flows, the temperature remains high. When the plug is functioning, the cold argon stirring gas decreases the temperature quickly from about 700 °C to about 200 °C inside the plug. Temperature changes in this range are particularly critical because refractory material in general behaves more brittle at such lower temperatures when compared to temperatures beyond 1000°C. Tabular alumina – spinel refractories provide the desired thermal shock resistance due to the blend of corundum and spinel with different thermal expansion, which reduces stresses in the material.

In addition, the wetting angle of liquid steel on spinel containing alumina refractories is increased beyond 90 degree so that an infiltration of the gas slits and clogging of the purging plug is hampered.

Conclusion

The examples of modern high alumina refractories briefly discussed in this paper demonstrate the contribution of refractories to modern steel making, both technically and economically. When considering the economics of refractory solutions, it is important to also take refractory related operational cost into equation, and not only focus on the directly spend refractory costs. Refractory related operational costs beyond purchase price and installation can be briefly summarised as follows: production losses due to unavailability of vessels (relining, lack of reliability, unexpected failure – or even worse, incidents), effect on steel quality, energy losses, yield losses, environmental, health and safety aspects, etc.

Experience shows that the refractory related operational costs have the same magnitude as the directly spend refractory cost, and a simple saving by purchasing cheaper, lower quality refractories is often a much more expensive solution when taking the refractory related operational costs into account as well. The flexibility required in modern steel making processes requires performance reserves in refractories. Siebring [12] stated in the refractory seminar of the Steel Academy: "Refractory is a tool to produce steel."

References:

1) R. Fandrich, B. Kleimt, H. Liebig, T. Pieper, F. Treppschuh und W. Urban: Stand der Pfannenmetallurgie und aktuelle Trends (Status of secondary metallurgy and present trends), stahl und eisen 131 (2011) Nr. 6/7, 75-89.
2) R. Bruckhaus, R. Fandrich: Trends in Metallurgy 2012, 55th International Colloquium on Refractories, Aachen, Germany, 19-20 September 2012.
3) A. Viertauer: Ladle Metallurgical Treatments & Refractory Stress for a Steel Teeming Ladle, Refractory seminar Steel Academy VDEh, Cologne, Germany, April 2012.
4) H. Lachmund: Demands on refractory material for secondary metallurgy, 7th international symposium steel ladle lining, Steel Academy VDEh, Hannover, Germany, September 2012.
5) M. Schnabel, A. Buhr, R. Exenberger, C. Rampitsch: Spinel: in-situ versus preformed – clearing the myth, Refractories Worldforum 2 (2) (2010) 87–93.
6) Franken, M.C.; Siebring, R.; de Wit, T.W.M.: New refractory lining for steel ladle BOS´no.2 Corus IJmuiden, UNITECR 2001, Cancun, Mexico, Vol I, 128-138.
7) I. Krausz, S. Everstein, S. van der Wal, T. de Witt: Increasing Steel Ladle Refractory Performance at Corus IJmuiden BOS 2, presentation at international symposium steel ladle lining, Steel Academy, Linz, 2006.
8) H. Lachmund: Demands on refractory materials for secondary metallurgy, presentation at international symposium steel ladle lining, Steel Academy, Hannover, 2012.
9) R. Exenberger: Steel ladle lining at voestalpine Stahl GmbH Linz, presentation at international symposium steel ladle lining, Steel Academy, Hannover, 2012.
10) Schnabel, M.; Buhr, A.; Van Garsel, D.; Schmidtmeier, D.; Zacherl, D.; Dutton, J.: Advantages of dense calcium hexaluminate aggregate for back lining in steel ladles, UNITECR´09, Salvador, Brazil, paper 049.
11) Dannert, C.; Köchner, H.: Monitoring of availability and reliable operation of purging plugs, MPT International 2010, 1, S. 24-25.
12) Siebring, R.; Buhr, A.: Economics in refractory usage, Steel Academy seminar refractory technology: application, wear mechanism, and failures, Cologne, April 22-25, 2012

Adaption of Corundum Refractory lining Technology in Lime Dolomite Calcination plant and Major capital repair technique through top-down approach at SAIL-IISCO Steel Plant

Prasanta Baidya[1,2] , B K Sinhamahapatra[1], Tarun Misra[1], V K Rai[1], M. Bose[1],
[1]*Refractories Department, Burnpur – 713325, W.B.*
[2]*Corresponding Author's e-mail: prasanta.baidya@sail.in*

Abstract

Lime Dolomite Calcination Plant is an integral and crucial part of any integrated steel plant as Lime & Dolomite play very important role for maintaining healthy balance sheet of that respective steel plant. ISP-SAIL is having total four shaft kilns for producing calcined lime & Dolomite. Three shaft kilns having capacity of 330 TPD are operation for lime production and one single shaft kiln having capacity 200 TPD is dedicated for dolomite production. All the shaft kilns consume mixed gas (Blast Furnace gas & Coke Oven Gas) as a fuel for the calcination process. However due to inconsistency in quality of gas, choking of combustion system occurs frequently and abnormally high numbers of shutdown become regular phenomenon at LDCP kilns and ultimately it leads to high thermal shock for the refractory used in LDCP lining which is primarily consists of Magnesite bricks. During last few years it has been observed that falling of refractory arch at shaft kiln dilutes reliability of LDCP production. Refractory department of ISP has made various changes in quality and design parameters in existing lining practices, like implementation of Corundum arch which is primarily α-Alumina(α-Al_2O_3) and is extremely thermal shock resistance compared to earlier Magnesite bricks even in that harsh condition. ISP have already installed this type of arch in shaft kiln-2&4 and planning to extend it to rest two kilns also as downtime due to refractory reason has become minimal now.

ISP Refractory team has also adapted new lining technique to fasten the capital relining work in minimum time frame by installing retainer, Tie-rod system and top-down lining approach without emptying the burden at a time. This type of practice has not only expedited the capital relining work speed but also taken care of maximum safety at that time. It has also minimized the job volume and maximized reuses of old bricks which directly reflected in financial data and leads to major cost saving.

Keywords – Lime Dolomite Calcination; Magnesite; Corundum; α-Alumina(α-Al_2O_3)

INTRODUCTION

Since the introduction of modern steel-making technology in the 1950s, magnesia-based refractories have major role in resisting the formation of slag in steels, thus increasing the service life of different type of steelmaking vessels (e.g., LF, BOF, RH, EAF etc). It has also played as supporting materials in the glass, cement, and non-ferrous industries for various high-temperature processes. China being primary source of various types of magnesia as well as largest global magnesite reserves it has crucial role on global magnesia supply and China has its own advantages due to its economically feasible manufacturing processes. High-grade magnesite ore has been mined to manufacture dead burnt magnesia (DBM) and fused magnesia (FM), which are both used as raw materials for the production of various basic bricks and MgO–C bricks. [1]

Uses of Magnesite bricks are very common practice at Lime Dolomite Calcination Plant; however, it has been observed when quality of gas is inconsistent and numbers of shutdown are significantly high, magnesite bricks unable to perform as desired level due to frequent thermal shock experienced by it. It has been found that Corundum which is primarily α-Al_2O_3 could be a very good alternative in that area as its thermal shock resistance is multi fold in comparison to Magnesite bricks and Thermal expansion co-efficient also in lower side which ensures more stability of refractory lining as well as less chances of failure/breakdown. A top down lining approach is also adapted to ensure maximum re-uses of old refractory lining to minimize the cost of capital repair.

Refractory selection for LDCP arch

Primarily two aspects have been taken care of during capital repair, one is replacement of arch of LDCP and second is relining of circular as well as straight wall with re-used bricks which are not damaged through top down approach. Earlier arch was made with magnesite-based bricks which is the mineralogical name for magnesium carbonate, MgCO3, and was one of the original sources for magnesium oxide used in refractory products. Its theoretical com- position is as follows: MgO: 47.7%; CO2: 52.3%, with traces of Fe; Mn; Ca; Co; N. having melting point at around 2800 ◦C. The decomposition of magnesite in an inert N_2 atmosphere can be represented as follows: $MgCO_3$ $MgO + CO_2$ **[2]** It usually have thermal expansion approximate 1.5% at 1200^{o}C and due to less thermal shock resistance frequent arch damage has been found which leads to greater downtime and also increased the consumption of castable and insulation items to minimize the heat at crossover area of arch due to the aforesaid damages whereas Corundum has only 0.5% at 1400^{o}C. This much expansion is actually ensuring to maintain stable arch condition at even very harsh operation condition. It has also been observed that due to fall of top arch, temperature at crossover area was reached above 300^{o}C now without any major filling/repair temperature is lying below 200^{o}C indicates the stability of current corundum arch.

Stability in wet environment& Dimension

Among the properties that form the logic behind selection of Corundum is its high stability in wet environment and dimensional stability due to its high density and absence of

Property	*Units*	*Value*
Crystallography	–	Hexagonal
Lattice parameter a	nm	0.476
Lattice parameter c	nm	1.299
Melting point	K	2310
Density (theoretical)	$g\,cm^{-3}$	3.986
Thermal expansion coeff.	–	6.5
Thermal conductivity (298 K, >99.9%TD)	$W\,m^{-1}\,K$	30
Specific heat (298 K)	$J\,Kg^{-1}\,K$	$8–10\times10^{-4}$

Fig.1.- Properties of Alumina based on data of Do¨rre and Hu¨bner[3] Li and Hastings[4] and Munz and Fett.[5]

open pores which restrict any intrinsic compound formation as microstructural defects or flaws. [6]

Capital Repair Techniques

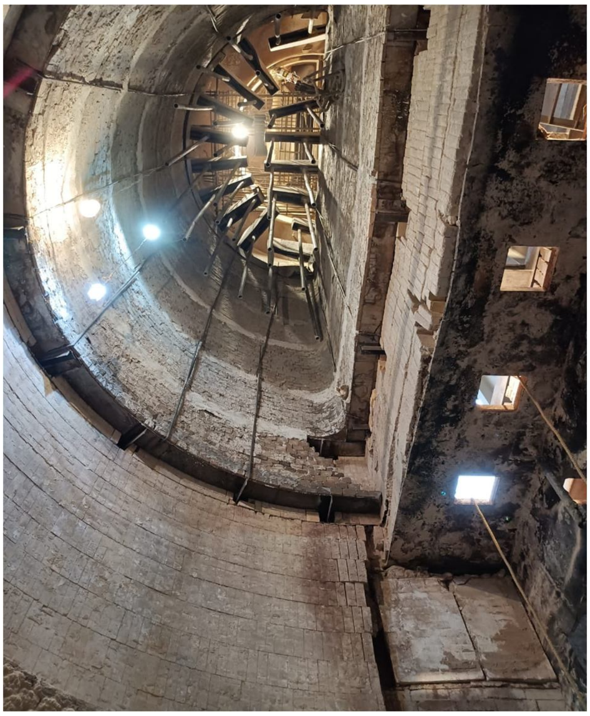


Fig. 2.- Inside the shaft kiln of LDCP ISP (Retainer plate & Tie-Rod Arrangement)

SAIL-IISCO steel plant also adapted top down lining approach during capital repair. In this technique once shaft kiln is taken down for repair, lining starts from the top segment wise and to minimize risk in every 15 layers retainer plate fitment arrangement is made along with tie rod assembly so that once lining approaches downward by lowering the charge burden upper segment do not fall. Apart from above mentioned advantage this technique also ensures the re uses of lining bricks specially alumina bricks used above lance area (Calcination zone) and Discharge zone (bottom of the arch). Debris are cleaned from the discharge chute area parallelly to save the downtime.

Financial Impact

At SAIL-ISP in LDCP area magnesite arch usually lasts 1~1.5 years approximately with out any major repair, post that major repair either by grouting/filling is required with high alumina based castable on the other hand Corundum arch (Till now two kilns are installed out of four) which is almost maintenance free from last 2.5 years and significantly reduces downtime due to the same. In cost comparison Corundum costs 1.36 times higher (Reference rate taken from 2020) than magnesite still due to less to nil maintenance and minimal downtime it actually enhances the productivity as well as saves cost in multiple way to maintain a healthy balance sheet.

Conclusion

No doubt corundum is better player for LDCP arch in every term where operation condition is too much volatile and required productivity is on higher side. However, it should be taken into account that corundum prices are usually higher than the magnesite used for LDCP arch, so it is always better to analyze all the parameters thoroughly based on that appropriate refractory should be chosen. Additionally, top down lining approach is a very good practice to save significant amount of time and money by re-using the old bricks which are in good condition. Installation of retainer and tie-rod also ensure the maximum safety during refractory lining.

REFERENCES

[1] Zongqi Guo, Qiang Ding, Lei Liu, Xiaohui Zhang, Xingyuan Luo, Feng Duan, “Microstructural characteristics of refractory magnesia produced from macrocrystalline magnesite in China” Ceramics International, (2021), 22701-22708, 47(16)

[2] Chaouki Sadik,Omar Moudden, Abdselam El Bouari, Iz-Eddine ElAmrani, “Review on the elaboration and characterization of ceramics refractories based on magnesite and dolomite” Journal of Asian Ceramic Societies, (2016), 219-233, 4(3)

[3] Do¨rre, H.; Hu¨bner, H. “Alumina: Processing Properties and Application.” Springer: Berlin, 1984; pp 9–79.

[4] Black, J., Hastings, G., Eds.; Chapman and Hall , “In Handbook of Biomaterial Properties” London, 1998; pp 340–354.

[5] Munz, D.; Fett, T. “Ceramics: Material Properties, Failure Behavior, Materials Selection.” Springer: Berlin, 1999; pp 9–18

[6] Piconi C, “Alumina” Comprehensive Biomaterials, (2011), 73-94

Introduction of slide gate system for drainage of hot metal from Trough in Iron Making

Suchit Kr Mahanta*, Gautam Kr. Choudhary, Shubhashis Paul, Sahin Ali, Utpal Chakraborty, Soumyadipta Das, Ujjwal Kumar, Deepak Kumar, Sunanda Sengupta, P.B Panda, **Dinesh Chandra Vishwakarma, **Mousom Bag & **Avick Ghosh
** TRL Krosaki Refractories Ltd., **Tata Steel Ltd*

Abstract

In an integrated steel plant, raw materials are processed in blast furnace (BF) to produce hot metal. From BF hot metal (liquid iron) is tapped through tap holes & is transferred to a refractory lined vessel called as torpedo ladle for transfer to further processing stations which involves conversion of hot metal to steel. Transfer from tap hole to torpedo vessel takes place through a refractory lined drain called Trough. Separation of liquid iron & slag is carried away in Trough by principle of difference in density with the help of Skimmer block. Metal drains through metal runner & slag through slag runner. Trough needs to be relined or repaired at regular intervals for continuity of operation as refractory has a certain life limitation. Before repair drainage of remaining hot metal from Trough is a pre-requisite. This is being done in a conventional process which has various associated challenges related to process and safety.

To overcome those challenges, a concept of slide gate like ladle slide gate system was developed. This system comprises of mechanism, refractory components & an actuator. This paper covers, conventional process of hot metal drainage & challenges associated with it, approach of developing a new concept of slide gate system for this application, design, trial details & merits of slide gate system over existing conventional system.

Keywords – Trough, Slide gate system, hot metal, lancing

INTRODUCTION

Hot metal from BF is transferred to Torpedo Vessel through Trough as shown in Fig.1.

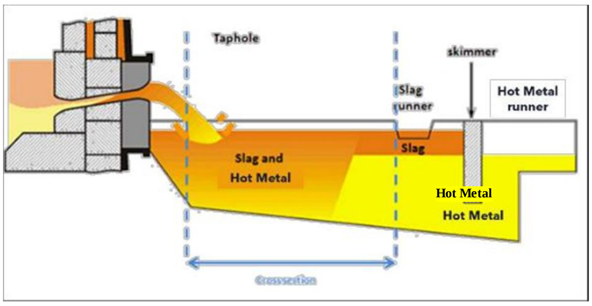


Fig.1 Discharge of hot metal

After complete discharge, In the Trough some amount hot metal is always remains in it depending upon the inner profile of Trough. As it's a refractory lined drain so regular repair is required for safe operation. Trough needs to be discharged during BF shutdowns & Trough needs to be taken under repair. Since beginning the drainage of hot metal from Trough is done in conventional process. One discharge hole is provided in the bottom portion of the Trough which is blocked during normal operation as shown in Fig.2.

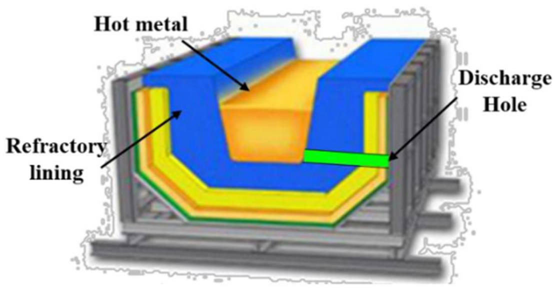


Fig.2 Trough & discharge hole

Discharge hole is blocked by plugging with ramming mass or hydrous clay and the length of the hole is around 1000mm and sometimes longer depending on size of Trough. Ramming mass gets sintered after sometimes which requires lancing during cleaning of hole. During drainage of remaining hot metal of Trough, the discharge hole needs to be cleaned which require rigorous lancing. Finding the actual level of discharge hole and straight lancing throughout the total refractory lining of the Trough is the key challenge in this process. As improper lancing/cleaning will lead to incomplete discharge of hot metal and will increase the downtime & loss of production. Even may lead to main trough failure extremely detrimental when BF gets repeated shutdown & multi discharged happens during mid-term campaigns. In addition to this lancing at discharge hole in a congested area is involved with high risk of burn injury from hot liquid metal or by lancing spatter. Easy closing and opening of discharge hole together with less or no lancing are the key demand from BF operation, leading to improve productivity & process safety without any compromise with drainage of Troughs.

AVAILABLE OPTIONS

Some options were available to solve the issues but also has some drawbacks like.

Open discharge hole with drill machine- Opening of hole with drill machine is possible but the key challenge is space constraint. As the space near the discharge hole is very less so it would be very difficult to perform the operation and there's chances of refractory lining damage.

Closing discharge hole with conical refractory plug- This practice is being followed in some shop in which around 1/3rd of the length of discharge hole a conical refractory plug is inserted from outside and the rest area is filled with ramming mass as shown in Fig.3. This process reduces the effort comparing with conventional process but still lancing is required and sometimes removal of plug gets very difficult. The most prominent drawback of this system is in any case the plug not fitted properly hot metal may be drained below the plug & may lead to failure.

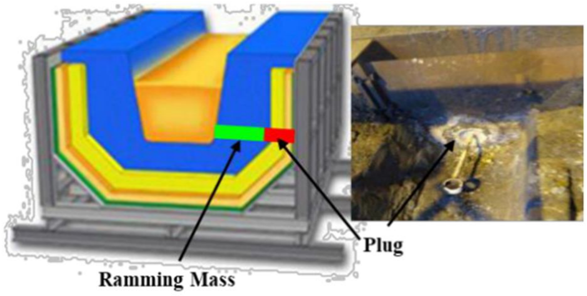


Fig.3 Plug type system

CONCEPTUALIZATION:

As available solutions still have some challenges, so it was decided to go with some new idea and ladle slide gate system concept was considered. Ladle slide gate is mounted underneath the steel ladle and used to control the flow of liquid steel from ladle to tundish. It is a mechanical assembly consists of some refractory components like nozzles and slide plates. Slide plate is reciprocated with the help of hydraulic actuator to control the flow as shown in Fig.4.

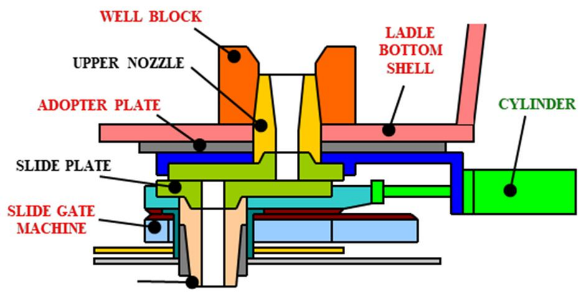


Fig.4 Ladle slide gate system

It was decided to design a slide gate mechanism for Trough discharge hole which will work similarly like ladle slide gate system and instead of using ramming mass, sea sand will be used for filling the discharge hole.

DESIGN OF TROUGH SLIDE GATE

One simple & robust slide gate mechanism was designed which will be fitted in the Trough Shell to control the flow of hot metal from discharge hole of the Trough as per requirement. Concept of slide gate for Trough discharge hole is very similar to ladle slide gate system but the operation practice will be quite different. In ladle slide gate online changing/maintenance of refractories are done as proper arrangements are provided but in discharge hole area those operations can't be performed due to space constraints. Refractory design also kept simple with integrated nozzle type design in which nozzle and slide plate will be one part to minimize joints as shown in Fig.5. Tension elements in the machine is provided to maintain face pressure between the plates to avoid metal penetration in between plates during discharge of metal. For actuation of plates hydraulic cylinder is provided and connected with slide frame by connecting rod.

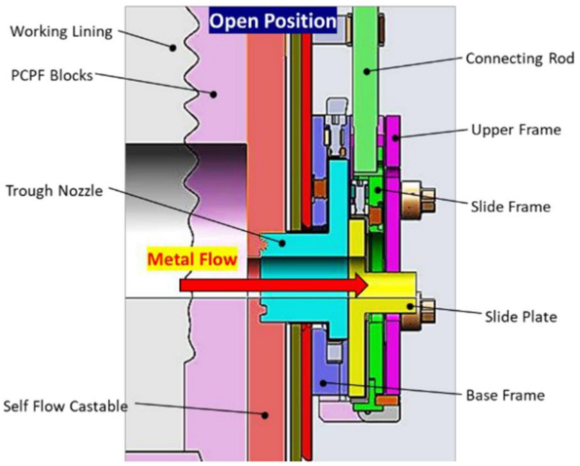


Fig.5 Trough slide gate system

PROCESS FLOW OF TROUGH GATE

All maintenance and preparatory jobs will be done offline in the cast house floor. Maintenance stand will be provided in which machine will be fixed and refractories will be fixed as shown in Fig.6. After fixing of

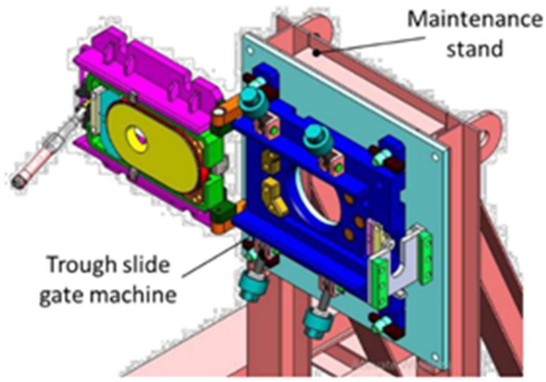


Fig.6 Preparation of Trough slide gate

refractory in the machine gate will be closed and face pressure loading to be done. After preparation, machine will be fixed in the base plate by bolting which is welded in the Trough Shell as shown in Fig.7. After that backup casting will be done which will lock the nozzle. Jig will be inserted in the nozzle before casting

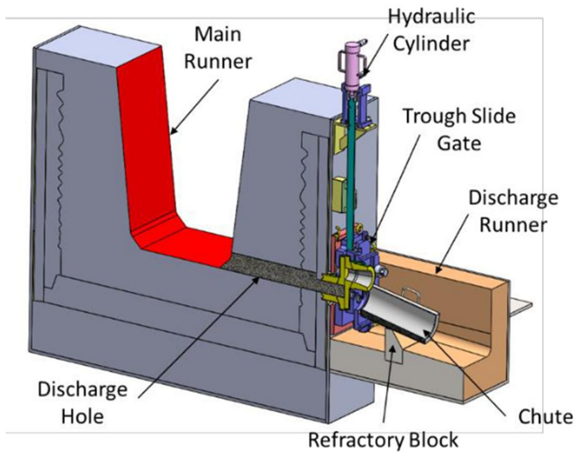


Fig.7 Arrangement of Trough slide

to maintain the discharge hole position. After casting is done jig will be removed and the discharge hole will be filled with sea sand. Trough will go for operation and at the time of discharge slide plate will be reciprocated to open position with the help of hydraulic cylinder. In open position sand cleaning with air to be done and if required minor lancing of sintered sand on hot face side to be done after that metal will start discharging.

COLD TRIAL OF TROUGH SLIDE GATE

After designing of all the machine parts mechanism was manufactured as shown in Fig.8 and cold trial of machine was done. Function of machine and all parts were found OK in cold trial. Hot trial to be conducted soon.

Fig.7 Cold trial of Trough slide gate

CONCLUSION

Using the slide gate system for Trough discharge will lead to no or very less lancing as instead of using ramming mass, sea sand will be used which can be cleaned easily. It will eliminate the hazards of burn injury from lancing in a congested area. It will also reduce the down time as hole will be cleaned easily.

Metal drainage will be maximum with a smooth flow resulting in reduction of relining cost as in conventional method due to improper lancing of hole some amount of metal always gets remained. This mechanized system will provide better drainage, better control & safety in the process. This will also help in increasing the productivity as downtime will reduce.

Way forward- as this is totally a new concept and hot trial is still pending, detail study of hot trial to be conducted.

REFERENCE

[1] The Making of Iron & Steel – SEAISI (Pg. 32 – 35)

[2] V. S. Sergienko, L. I. Krupman, V. A. Butkov, V. P. Shevchenko, L. G. Dubrovskii, A.N. Mozgovoi, A. A. Kortel, L. T. Oleinik, T. V. Dubovik & L. I. Struk: Refractories for the Slide gates for molten steel

Development of a New Refractory Repair Technology in Hot Blast Stove in pressurized condition at SAIL-IISCO Steel Plant

B K Sinhamahapatra[1a], Tarun Misra[1], V K Rai[1], M. Bose[1], C. L. Gaikowad[2],Shaubhik Roy[2]
[1]Refractories Department, SAIL-IISCO Steel Plant, Burnpur – 713325, W.B., India
[2]. Blast Furnace, SAIL-IISCO Steel Plant, Burnpur – 713325, W.B., India
[a] Corresponding author's email: bk.mahapatra@sail.in

Abstract

Hot blast stove is one of the most important apparatus for blowing hot air inside the blast furnace which is a very important step in increasing efficiency of iron making and reducing specific consumption of coke. Reliability of the hot blast stoves is of great concern to all blast furnace iron makers. During the course of operation, the stoves go through off-blast and on-blast modes cyclically. The refractory linings inside the stoves are subjected to repeated exposure of thermal shock and thrust of air which leads to degradation of vulnerable parts of the linings. Repair of lining defects are carried out by injecting refractory mortars or various pumpable refractories. But to carry out injection work, the system should have negative pressure inside so that hot gases does not come out when holes are cut/drilled for injection. But in case of ISP's stoves, the situation is opposite. The design does not have provision of connecting the stoves to chimneys having sufficient draft to create suction at the dome of the stoves. Therefore, hot gases started to come out when opening is created at the dome of the stoves, and the area becomes red-hot. The dome temperature of the stoves was reduced and water spraying was adopted for cooling of the shell from outside to prevent shell failure. A new repair method has been developed in drilling, fixing nozzles and use of valves of specific design with specific tools. All material, tools and tackles sourced indigenously. Nozzles and valves have been installed at the hot spot areas pre-identified with the help of infra-red thermal scanner. A ceramic fiber based pumpable refractory was used to carry out the repair. The material was injected at required depth and at the predicted defect-zones of the refractory lining of the dome. After refractory injection, the hot spots disappeared and water spraying not required. Steel shell surface temperature reduced below 100 ^{o}c from earlier above 300 ^{o}c at hot spots. Normal refractory operating parameters of the stoves were restored.

Keywords - Hot Blast Stove; Refractory Injection; Ceramic Fiber; Hot Spot

INTRODUCTION

The blast furnace of ISP has 3 nos. of Cowper type internal combustion hot blast stoves. As it is an integrated steel plant with a single blast furnace, during commissioning phase of the plant, operations of the Blast Furnace did not go smoothly. Throttling of production and shut downs of the furnace occurred multiple times. Shell temperature started to rise at certain areas of the bustle main, hot blast main and dome of stoves after approximately two years of commissioning. At some places of the bustle main, swelling of the shell observed which was repaired successfully by cutting the affected shell plates. Temperature surrounding the pyrometer flange of dome of stove no. 1 reached very high. An attempt was made to repair the refractory lining inside the pyrometer flange during blast furnace shut down. As the valve was opened, hot gas started to emit through the flange and the flange become red hot. Somehow the valve was closed. Several attempts were made thereafter but suction in the dome area could not be established. Cold repair can take more than a month time and during this time operation of the furnace with 2 nos. of stoves is very costly and not desirable.

However, normal repair methods are ruled out due to unsafe working conditions. Prediction of location and type of damage and reaching of repair materials to the damaged areas under pressurized dome is the main challenge for solving the problem.

Finally the repair had been carried out by developing a method which allows safe injection of refractory paste into the refractory lining inside a vessel with higher than atmospheric pressure.

LOCATION OF HOT SPOTS

Location of hot spots were mapped with the help of a Thermal Imaging Camera. Most of the severe hot spots were found at the top of the domes surrounding the dome plug. Severity reduced gradually towards the base of the dome. In the Hot Blast Main, severe hot spots observed at the junction areas of Hot Blast Outlet and Hot Blast main.

REFRACTORY LINING PATTERN IN THE AFFECTED AREAS

In the dome, dense silica bricks have been used as working lining followed by two layers of insulation and a layer of fireclay gunning castable lining adjacent to the shell. The lining pattern is shown in Fig. 2.

In the Hot Blast Main, working lining is constructed with Andalusite based dense bricks followed by two layers of insulation bricks and fireclay gunning mass adjacent to the shell as shown in Fig. 3.

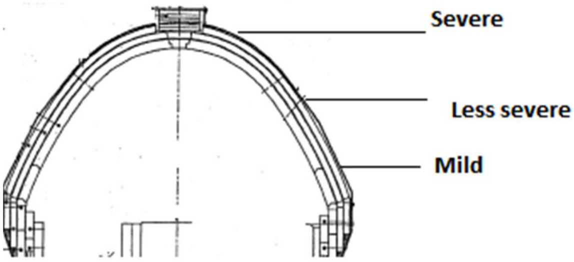


Fig.1: Location and severity of Hot spot zones at the dome [1]

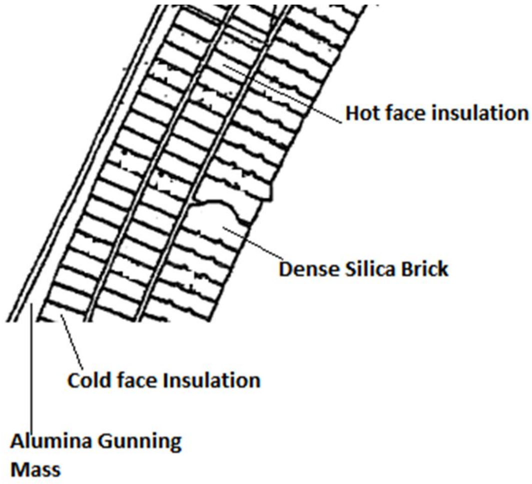


Fig. 2: Refractory Lining Pattern of dome[1]

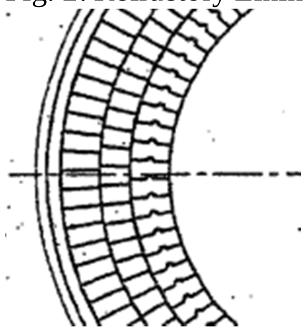


Fig 3: Refractory Lining pattern of Hot Blast Main[1]

PREDICTION OF THE FAULT

As hot blast stove is a closed vessel, it is very difficult to assess the type or extent of damage even during shut down. No defect in the working face of the dome was observed during the endoscopy although only a limited area attached to the combustion chamber were visible through endoscopy [2]. Damage behind the working lining is not easy to predict accurately.

As the ISP’s stoves are new, deterioration of refractories by chemical attack by alkalis or cyanides is not likely [3], [4].

As the initial development of hot spots were started from pyrometer areas of the domes and thereafter it increased gradually over past four years, it can be stated that there is no collapse in the working lining. However, due to cyclic fluctuations of temperature during operation, refractory linings expands and contracts regularly. This leads to thermal stresses and strains across the linings. Effects are maximum at the ends of layers/segments and joint areas. Moreover, during each cycle of Heating (On Gas) and cooling (On Blast) the stove is de-pressurized and pressurized. Abrasion among bricks cannot be ruled out and because of this mortars at brick joints likely to get washed out. Surface of the bricks may get eroded especially in case of insulation bricks. These effects create gaps in the lining through which hot gas can pass easily. Due to circulation of hot gas through gaps/cracks of the lining, convective heat transfer takes place and as a result, hot spots are created. If the cracks or gaps are not filled or repaired, damages continuously increases with passing of time.

Suspected areas were scanned by thermal imaging camera. High temperature zones of the shell surface were detected and marked.

REPAIR METHOD

The predicted defects generated in the insulating layers is the probable root cause of the hot spots at the hot blast system. So injection of suitable refractory materials can seal the cracks and openings of the insulation linings which will prevent passage of hot gas across the layers. In the hot blast main and bustle main areas negative pressure can be created through back draft chimney during shut down of the blast furnace. So injection of refractory can be done during furnace shut down by cutting/drilling of the shell and fixing or welding of nozzles.

But, in the dome of stove creation of suction is not possible through natural draft. So we have to carry out injection at a pressure higher than atmospheric pressure and take care of ejection of flame by some means.

To prevent ejection of flame through the drilled hole, nozzle with valves were fixed with the shell by partial drilling and tapping threads inside the hole. Then another hole was drilled through the valve and nozzle to puncture the shell and valve was closed as soon as the drill was withdrawn. Further drilling of the refractory done through the gunite layer into the insulation layers to get access of the appropriate level for installation of injectable refractory. Pumpable refractory injected through these nozzles inside the vessel by an electric screw pump. A pressure gauge was installed in the delivery line of the pump to monitor the pressure online during injection. When back pressure started to increase steadily, pump was stopped and pressure did not drop. This indicates no further flow of material inside the vessel and injection is complete.

SELECTION OF MATERIAL:

As the defect is in the insulating layer, the pumpable refractory must be insulating quality. Desired quality of the pumpable are- flow ability, solid content, thermal conductivity, and development of strength after installation, temperature resistance and should not contain any volatile or flammable material. Properties of used material shown in Table 1.

Table 1 Properties of the pumpable

Major Components	Alumina (%)	45
	Silica (%)	50
Solid content	(wt%)	40
Density (Dry)	g/cc	0.52
Classification temperature	°c	1400

OFFLINE TEST FOR INJECTION OF THE MATERIAL

A simulative test was carried out offline to verify whether the material and injection arrangement is suitable to fill up narrow cracks and gaps of the insulating layers. Inside of a steel pipe of 350 mm diameter and 1500 mm length was lined with insulation bricks and closed from both sides. One nozzle and valve fixed at the curved surface. The pumpable injected through the nozzle and when pressure started to increase, hold at 4.5 kg pressure for 1 minute and thereafter the pressure released. Flanges opened and penetration of the pumpable mass at joint of bricks observed.

Fig. 4 shows the lining surface after pumping. Joints and cracks are filled with pumpable material. The lining was dismantled and it was observed that the pumpable has penetrated and spread evenly along the surface of bricks as shown in Fig. 5.

Fig.4: Test surface after removal of side flange

Fig. 5: Bricks at the centre of the lining shows the pumpable is evenly filled in the gaps.

REPAIR OF DOME AND HOT BLAST MAIN WITH PUMPABLE

Repair of the Hot Blast main junction carried out during off blast of the furnace. Hot spot appeared at the top of all the junction areas of the hot blast main and hot blast outlet pipe of 3 nos of stoves. 2 to 4 nos. of nozzles with valves as shown in Fig. 6 were screwed in by drilling of the shell. A portable Magnetic Drill machine was used.

Injection of pumpable was carried out one by one in all the nozzles at 4 to 4.5 kg delivery pressure. An electric motor driven positive displacement pump was used for pumping of material.

In the dome areas injection carried out in running condition of the blast furnace. Drilling, fixing of nozzles carried out when the particular stove was on heating mode. Schedule was carefully maintained with close coordination with the stove operation team to ensure safety in working.

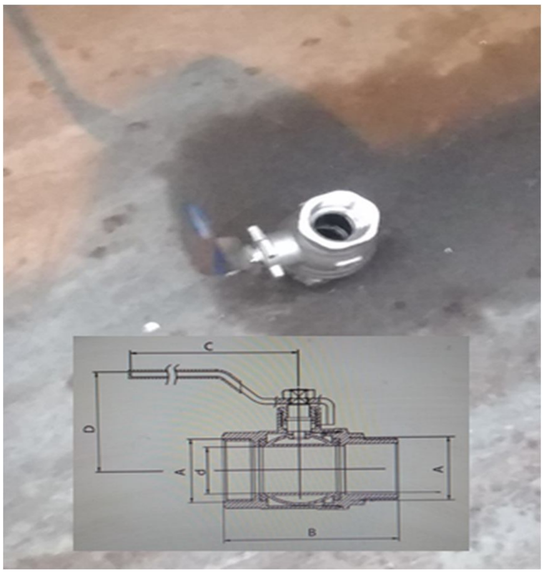


Fig. 6: Nozzle and valves fixed at the hot spot

RESULT AND DISCUSSION

Before injection repair, shell temperatures in the hot spot areas ware in the range of 160 °c to 320° c which dropped down in the range of 60°c to 100 °c. External water spraying on shell has been stopped.

Several sessions of injection required periodically as new hot is shifted to other location. This happens probably sometimes log channels of passage of hot air developed. If a channel is blocked by injecting refractory material at some places path of gas flow changes to other paths with lower resistance. During course of use, the injected material also may degrade over and further reinforcement may be required. Keeping the above fact in mind, the pumpable refractory injection program has been scheduled in phases during one year period.

CONCLUSION

1. Defects in the insulation layers of the hot blast system of a blast furnace can be successfully repaired using ceramic fiber based pumpable refractory.
2. The technology developed at SAIL-ISP can be used for online repair of hot blast stove without isolating the stove or taking shut down.
3. The above technology ensure safety of the workmen from injury by hot gas/steam which may come out if the vessel have higher than atmospheric pressure. Coming out of hot gas or steam can be controlled or stopped by closing the valve as and when required.

REFERENCES

[1] MECON Ltd. "SAIL-ISP Drawings"

[2] Yasuhiro YAMADA, Naoki TSUTSUI, Masahiko AMANO, Toshinori SUZUKI and Hiroaki OHTSUBO, "Observation and repair of Hot-Blast Stove at High Temperature," NIPPON STEEL TECHNICAL REPORT No. 98 JULY 2008

[3] A. S. Sarcar, B. N. Ghosh, B. Rao and K. S. Swaminathan, "Repair and Maintenance Practices of Blast Furnaces and Hot Blast Stoves," Transactions of the Indian Ceramic Society, 41:1, 17-21, DOI: 10.1080/0371750X.1982.10822562.

[4] Kotov, K. I., Rovenskii, M. I., Pryadko, V. M., &Magala, V. S. (1969). Causes of failure of refractory structures in the stoves and hot-blast tract of blast furnaces. Refractories, 10(11-12), 747–750. doi:10.1007/bf01290532

A Novel approach to reduce Torpedo ladle preheating time by introducing no cement bonded spout castable

Biswajit Sahu*, Manoranjan Kumar Singh, Avinash Singh, Prasanta Panigrahi
Tushar Agrawal, Sujat Ali Khan, Brijender Singh
TATA STEEL, Jamshedpur, India
Mail id: *biswajit.sahu@tatasteel.com

Abstract

The steel industry contributes to about 5-8% of global emission and considered to be a 'hard to abate sector' since carbon is used as a reductant in the steelmaking processes. Preheating of refractories consumes significant amount of CO gas and time to achieve desired refractory quality. Considering the amount of energy consumption, effort been made to use no cemented bonded castable. Torpedo ladle is critical for hot metal transportation from Blast furnaces to LD/SMS Shops. Considering the limited fleet, which is required for daily production; Low torpedo availability can lead to low Hot metal buffer & interruption in Hot metal supply to LD/SMS Shops. Relining is a major activity (longest downtime) of torpedo maintenance. In this work, the performance of CAC based castable and newly developed no cement bonded castable (NCC) compared and analysed. The new torpedo spout castable exhibits higher drying speed with better high temp. properties like strength, HMOR, Slag corrosion resistance, abrasion resistance and lower thermal conductivity compared to existing low cement based castable. By using this new torpedo spout castable, preheating period reduced by 34hrs at our Tatasteel , Jamshpedur works, which caused in considerable reduction of CO gas consumption by 30% and resulted in lower carbon footprint. Improved torpedo spout performance also contributes economical benefits by lowering the repairing material consumption like hot gunning.

Keywords: Refractory, Torpedo ladle, no cement bonded castable, Preheating period, Carbon footprint

1. Introduction

Torpedo availability is critical for hot metal transportation from Blast furnaces to LD Shops considering the limited fleet, which is required for daily production at Tata Steel, Jamshedpur plant. Low torpedo availability can lead to low HM buffer & interruption in HM supply to LD Shops. Relining is a major activity (longest downtime) of torpedo maintenance so reduction in torpedo relining turnaround time will increase the availability of torpedo.

High alumina cement, the conventional binder for alumina based castable containing CaO, is not suitable for very high temperature applications due to different low melting phase formations.

In order to minimize these drawbacks, the properties of the refractory castables were improved by decreasing the cement content, giving rise to a shift from regular cement castables towards LCC (low cement castables), ULCC (ultra-low cement castables) and lately cement-free castables [9–11]. Different calcium-free binding systems such as hydratable alumina (HA), colloidal silica (CS) and colloidal alumina (CA) have been developed for refractory castables [13]. During heating,the hydrated phases lose their chemically bound water, giving rise to the stable form of alumina (α-Al_2O_3), which at higher temperatures will help to develop a strong ceramic bond [1, 7]. However, the use of hydratable aluminas also present limitations, such as the high likelihood of explosive spalling during drying, because of its less permeable structure when compared with a cement based composition [1].HA-bonded castables demand longer mixing time and high-water contents due to the high specific surface area of the binder [9-12]. Moreover, after hardening, HA-containing castables results in a much less permeable structure when compared to CAC-based ones, which leads to higher explosive spalling likelihood during the water dry-out [4-7].]. At first, the addition of colloidal alumina had been restricted to contents lower than 1 wt% [10,11], most likely due to processing difficulties such as high-water demand and low flowability and workability. High water demands lead to poor high temperature properties. The gelling mechanism of colloidal silica containing composition generated a high-permeability structure, facilitated water removal, preventing spalling. colloidal silica particles also improved the system's reactivity, increasing the castable sinteribility, promoting mullite formation [1]. Absence of impurity and any liquid phase formation in the developed castable system makes it suitable for very high temperature applications [2,15]. Due to the low water content the castables decreased in porosity and gained in strength. Therefore, with regards to refractory applications such as slag infiltration or wear resistance low cement castable show better performance [3]. However, the high density makes the drying process more complex [4]

Literature does not provide any work on the use of only silica sol as sole binder (without any cement) in castable system for torpedo mouth application and such an attempt has been made in the present study.

2. Current Practices and methods

At Tata Steel - Jamshedpur works; a fleet of 48 refractory-lined, steel torpedo ladles are used to transport the hot metal from six Blast Furnaces to three LD shops. There are two types of torpedo ladle, consisting of 320Mt capacity and 200Mt capacity. . At present 21nos of 200t and 27nos 320 t TLCs are in fleet to transport 32000 tons of hot metal per day.

Refractory performance in torpedo ladles also plays a vital role in maintaining availability by improving campaign and reducing downtime for regular maintenance. Continuous improvement of refractory quality to reduce corrosion and thermal shock had been carried out. Further improvement plan has been undertaken to reduce chemical reactions in refractory lining with hot metal and slag especially in spout areas of torpedo ladle.

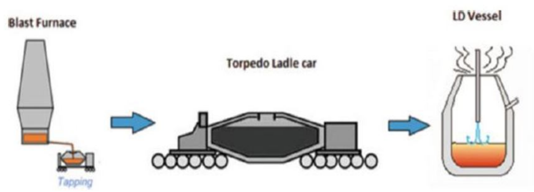


Fig. 1: Transport of hot metal

The general arrangement drawing of 320t and 200 t torpedo Ladle car is shown in Fig – 2 and Fig-3.. The vessel is of fabricated design having barrel – venturi – charge pad- spout area, duly lined with refractory bricks/castable. The technical specification along with brief description is given in Table 1. Current zonal refractory lining practices in 200 t and 320 t TLCs shown in Fig – 2 and Fig – 3.

Table-1. Technical specification of Torpedo ladle cars

Parameters	320t TLC	200t TLC
Vessel capacity with new lining	320t	200t
Hot metal temperature (deg C)	1550	1550
Weight of TLC (without refractory)	180 ton	113 ton
Weight of TLC (with refractory)	300 t (approx)	218t
Inside volume of vessel with new lining	51.23 m3	39.5m3
Available free board	2.27 m3	1.8m3
Overall height of car above rail top	4350 mm	4110 mm
Overall width of car	3500 mm	3428mm
Max. permissible shell temperature	300 deg C	300 deg C
Overall refractory thickness	400 mm	400 mm

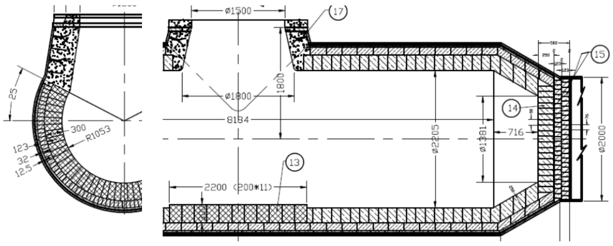


Fig. 2: Lining configuration of 200t torpedo ladle

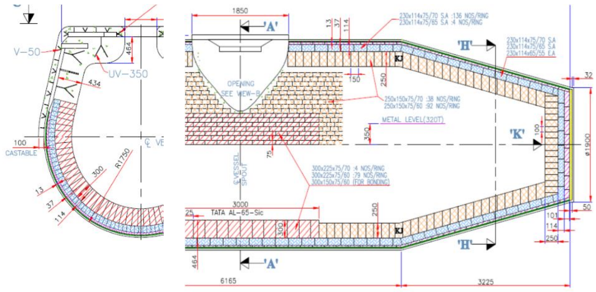


Fig. 3: Lining configuration of 320t torpedo ladle

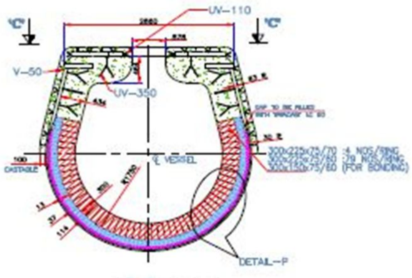


Fig. 4: Lining configuration of spout portion of 320t torpedo ladle

Till mid-90s, 90 % alumina low cement castable was considered as one of the best material available for use in lining the mouth area of TLCs. With changes in hot metal chemistry, higher hot metal temperature and higher casting rate, use of better quality castable was considered. low cement – self flow castable with superior thermal shock and corrosion resistance was introduced over a period. (shown in Fig-4)

Due to wear mechanism of refractory over a period of usage, new lining is carried and it takes around 452 hrs including refractory and other maintaence activities (Shown in table no-2), which is the total turnaround time required for a torpedo before going into the hot metal circulation.

Table-2. Activities performed for Torpedo repairing

Sl no	Activities details	Time(Hours)
1	Cooling	16
2	Dismentling	64
3	Mechanical+ Elecrical+other repair	48
4	Refractory relining	204
5	End wall lining, shield plate casting and end cover closing	24
6	Heating	96
Total		452

2.1 Current challenges

- High Hot metal production
- Cost pressure
- Carbon footprint reduction- Environment friendly
- Easy, flexible and safe workability

Low cement castables, having cement in the range of 4–6 wt%, have improved the properties at high temperatures but still the formation of liquid phases remains, when castables are applicable up to 1550°C. Above this temperature, the formation of low melting compounds, namely, anorthite ($CaO \cdot Al2O3 \cdot 2SiO2$) and gehlenite ($2CaO \cdot Al2O3 \cdot SiO2$). Due to formation of these low melting phases, high temp. properties degrade drastically. Torpedo spout areas castables undergoes though different physical and chemical phenomena like BF slag reaction, impact of hot metal and slag, thermal shock during circulation. The shell temperature near spout area also remained to be within 300 deg. C.
Due to high metal production over the years, availability of torpedo ladles became a perennial issue at our Jasmshedpur works. Relining is a major activity (longest downtime) of torpedo maintenance. so reduction in torpedo relining turnaround time will increase the availability of torpedo. Current turnaround time for a newly lined

torpedo 452 Hours, which includes 96 hours. of preheating schedule.

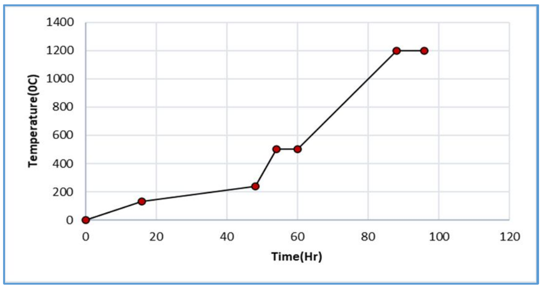


Fig. 5: Existing heating schedule of new relined torpedo

3.Experimental Procedures

The experimental work consists of two different types of silica-sol bonded products. Their main characteristics are shown in **Table -3** and compared with the existing torpedo spout castable.
Two types of sol bonded castables selected for torpedo spout application. Physical, chemical, thermal characterization of different castables evaluated at our RTG - lab using usual techniques. Chemical analysis of the samples was done using Inductively coupled plasma mass spectrometry (ICP-MS) method. Bulk density (BD) , Permant liner change (PLC) were determined by ISO-10570 standard and Tata Steel standard. The samples characterization was carried out by thermal spalling test as per DIN 51068, part 1(water quenching) test.. The slag corrosion test is conducted at 1500^{0}C for 3hr with Blast furnace slag in a static crucible sample of size 50 mm diameter and 50 mm height and cavity of 25 mm diameter. The same firing process is repeated 3 times to understand the corrosion effect of the slag on the refractory sample. DSC-TGA was employed to observe the temp Vs. weight loss behavior of the existing and Sol bonded sample qualities. Analysis of different phases present in the sample were conducted using XRD with energy dispersive spectroscopy (EDS) unit. Thermal conductivity of samples measured through Calorimeter method. The thermal expansion values also measured though Dilatometer instrument.

Table-3. Comparison test results of Low cement and Sol bonded castables.

Sample type	Existing castable	Trial sample-1 (T-1)	Trial sample-2 (T-2)
Base material/ Bonding type	High Alumina Cement bonded	Mullite based Silica Sol bonded	Al2O3-SiC based Silica Sol bonded
CHEMICAL ANALYSIS(%)			
ELEMENT DESCRIPTION	ANALYSIS		
CaO	2.42	0.6	0.5
SiO2	9.9	31.28	27.22
Fe2O3	1.07	1.04	1.18
Al2O3	83.03	63.36	56.47
TiO2	2.26	1	1.09
SiC	-	-	11.78
OTHER PROPERTIES			
WATER (%)	6	-	-
Silica SOL (%)	-	8.3	8.9
@110^{0}C BULK DENSITY(g/cc)	2.8	2.42	2.42
@110^{0}C POROSITY (%)	14.7	14.22	15.2
@110^{0}C CCS kg/cm2	640	600	580
@1000^{0}C BULK DENSITY(g/cc)	2.77	2.43	2.42
@1000^{0}C CCS (kg/cm2)	780	825	927
@1000^{0}C PLC(%)	-0.24	-0.06	-0.04
@1400^{0}C BULK DENSITY(g/cc)	2.73	2.44	2.44
@1400^{0}C CCS (kg/cm2)	867	945	962
@1400^{0}C PLC(%)	0.59	-0.19	-0.1
Corrosion Index	++	++	+
RTE @1000^{0}C(%)	0.75	0.5	0.62
Thermal conductivity' @800^0 C(W/mK)	1.78	1.47	1.46

4. Results and discussions

4.1 Chemical composition

The chemical composition of the existing spout castable and trial sol bonded samples are given in **table 3**. The existing castable contains 85% alumina, which is more than both trial sol bonded samples. (T-1&T-2). Very low lime percentage found in case of both trial Sol bonded castables due to usage of silica sol as binder in place of high alumina cement. Trial -2 contains Silicon carbide, whereas no SiC is present in trial-1 and existing castable. Impurities like iron oxide % found comparable.

4.2 Physical properties

The properties like bulk density (BD), strength, PLC values are shown in **Fig-6,7.8** Density values decreases at high temp. in case of existing cement bonded castable. Low density found in sol bonded materials(T-1&2) as compared existing material. No change in density in case of sol bonded castable at high temperature.

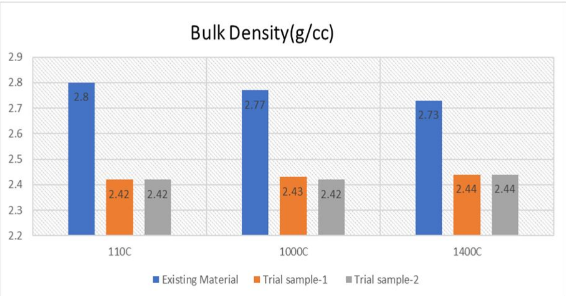


Fig. 6: Bulk density values at three different temperature

At 1400 deg C, higher strength (CCS) values observed in case of sol bonded trial castables. However, Strength values are found comparable with the existing cement bonded castable at 110 &1000 deg C. High strength observed due to network formation, sintering and mullite formation. The strength of sol bonded castables increases with increase in temperature. (shown in Fig-7)

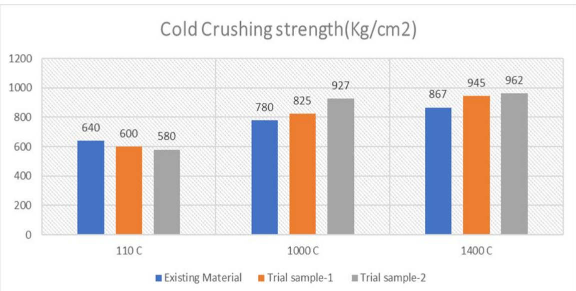


Fig. 7: Strength values at three different temperature

Minimal shrinkage observed in both sol bonded trial castable(T-1&2) compared to existing low cement castable. Expansion observed at 1400 deg C in existing castable. This mighty be use of bauxite as as a prime raw material in the composition.

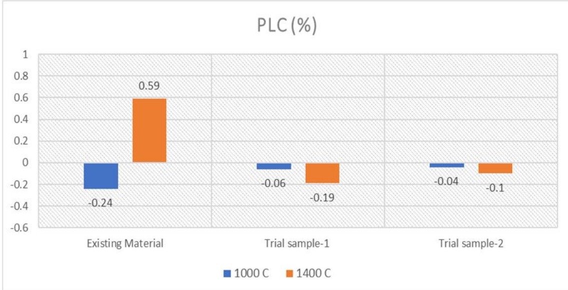


Fig.8: PLC values at three different temperature

4.3 Thermomechanical properties

Slag corrosion resistance

The relative corrosion index is shown in table 4, and conditions of samples after the slag corrosion resistance test is shown in figure 9. The samples that contain Silicon carbide have comparatively better corrosion resistance than the existing castable and mullite based sol bonded material.

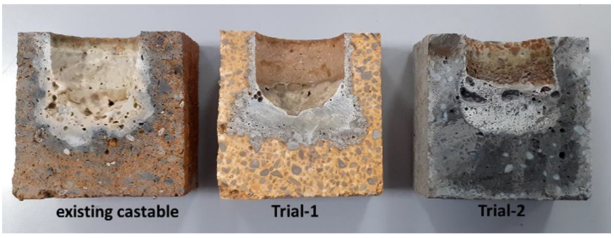


Fig.9: Corrosion test with BF slag after firing at 1500 C/ 3hrs

The slag corrosion test reveals that sol bonded sample (T-2) with silicon carbide have the good corrosion resistance against blast furnace slag as shown in **Table-4.** Corosion index also found very low in SiC based trial sol bonded castable.

Table-4. Slag corrosion index

Corrosion index		
Existing material	72.20%	++
Trial -1	80%	++
Trial -2	26.50%	+

Spalling resistance

Spalling also plays a major role in case of torpedo ladle due to its operational requirement like filling of hot metal at BFs and emptying it in LD shop. The appearance of the sample after 50 cycles the spalling test in water quenching at 1000 degree C is shown in Figure 8. No crack observed in all the three samples (existing, T-1& T-2).

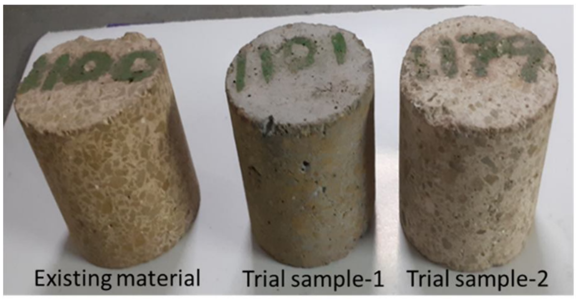


Fig.10: Results of thermal spalling after 50 cycle

Thermal Conductivity

Thermal conductivity values measured by water calorimeter method at different temperature (600, 800,1000 deg C) (shown in Fig. 11).

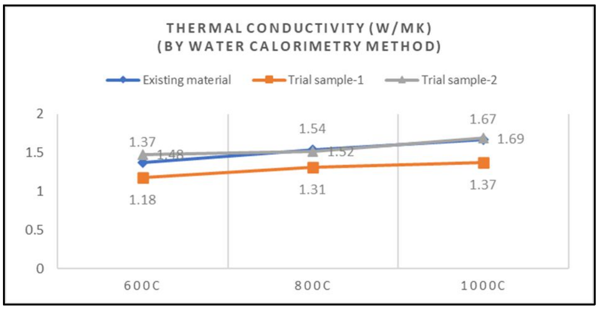


Fig.10: Results of thermal conductivity test

Thermal conductivity values of SiC containing sol bonded castable (Trial-2) and mullite based sol bonded sample (Trial-1) found comparable with the existing spout castable. Shell temp. values

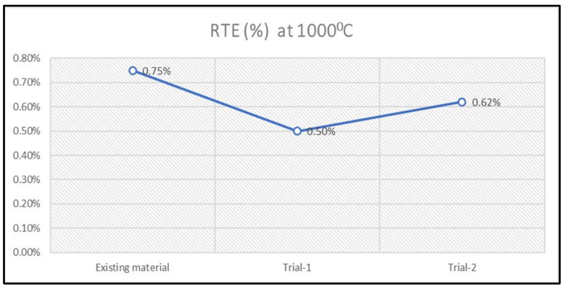


Fig.11: Thermal expansion % at 1000 deg C

Thermal expansion values measured at 1000 deg C for all the three samples in oxidizing atmosphere. Trial samples are having low expansion values than the existing one due to changes in chemistry.

5.Application of Trial castable

SiC based sol bonded castable shown better refractory properties (Trial Sample-2) as compared to the existing cement bonded castable and the other mullite based sol bonded material.

- Better high temp. properties
- High corrosion resistance against BF slag
- Comparable thermal conductivity values

Based on all the analysis; **SiC based sol bonded castable** finalized to take trial for Torpedo Mouth application and to validate the actual performance at the site.

We have applied this the material in one newly relined torpedo ladle spout (TLC N#41) at our Tatasteel-Jamshedpur plant. Details of the trial summery attached in the table -4. Torpedo heating sechdule reduced by 34hrs after using the trial spout castable. (shown in Fig.14).

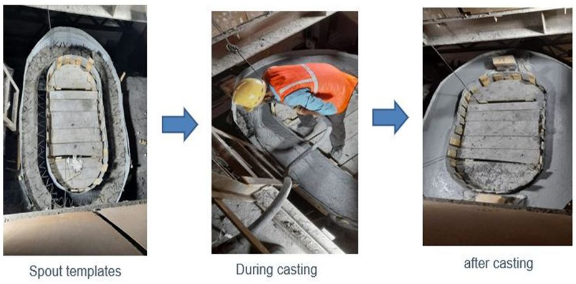


Fig.12: Spout casting using Sol bonded trial castable

Table-4. Trial Summary

Date of Trial	15-05-2022
Torpedo No	41
Material used	Sol bonded castable
Application area	Torpedo mouth/ Spout
Qty of material used	~ 8Mt
Binder used	Silica Sol
Binder addition (%)	9.5
Template removed	after 24hrs of casting
Heating period	62 hrs

Fig.13: Condition of torpedo spout after preheating

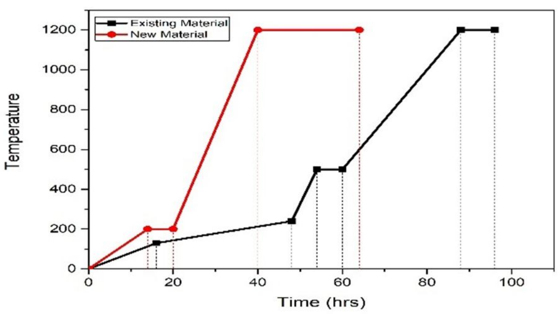


Fig.14: Comparative heating schedule existing vs Trial

6.Conclusion

Having performed comparative study and evaluation of low cement based (existing) and Sol bonded trial castable (Trial material no-2), following extrats can be propounded.

- Very rapid heat up possible due to absence of chemically bonded water
- High alkali and sulphur resistance as no calcium aluminate (CA) phases)
- Very long shelf life. No binder in the dry mix
- Very good flexibility and thermal shock resistance
- Long shelf life (18 months) compared to LCC.
-Remarkable time and energy savings due to easy drying behaviour compared to LCC.
- Reduction of CO gas consumption by 30% and resulted in lower carbon footprint.
- Better high-temperature properties result in longer campaign life and reduced downtime of operation.
-Lower consumption of repair material (like gunning consumption) due better high temp. properties
- Mullite formation improves the corrosion resistance and hot strength properties.
-Shell temperature found within the safety norms (<300 Deg C) due to lower thermal conductivity values
- Presence of SiC in the matrix improved the corrosion resistance against BF slag

So, we preferred the Sol based castable (NCC) for torpedo spout application to achieve the hot metal logistics requirement for LD shops.

Acknowledgments

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References

[1] S. Banerjee, "Monolithic Refractories–A Comprehensive Handbook," Singapore: World Scientific/The American Ceramic Society, 311p (1998).

[2] S. Banerjee, "Recent Developments in Monolithic Refractories,"Am. Ceram. Soc. Bull., 77 [10] 59-63 (1998).

[3] R. Kockegey-Lorenz, A. Buhr, D. Zacherl, B.Long, S. Hayashi and J. Dutton, "Review of Matrix aluminas for refractory formulations," in UNITECR 2011, Kyoto, Japan, 2011: 2-B2-9

[4] D. Bell, "Development of a computer program to model drying of castable blocks and linings,"Refractories Applications and News, 2005, 10(2):18-22

[5] F. A. Cardoso, M. D. M. Innocentini, M. M.Akiyoshi and V. C. Pandolfelli, "Effect of curing time on the properties of CAC bonded refractory castables," Journal of the European Ceramic Society, 2004, 24(7): 2073-2078

[6] G. Palmer, J. Cobos, J. Millard and T. Howes"The Accelerated Drying of Refractory Concrete

[7] S. Klaus, J. Neubauer and F. Goetz-Neunhoeffer,"Hydration kinetics of CA2 and CA -Investigations performed on a synthetic calciumaluminate cement," Cement and Concrete Research, 2013, 43: 62-69

[8] M. D. M. Innocentini, F. A. Cardoso, M. M. Akiyoshi and V. C.Pandolfelli, "Drying Stages During the Heat-up of High-Alumina, Utra Low Cement Refractory Castables," *J.Am. Ceram. Soc.*, **86** [7] 1146-1148 (2003).

[9] S.H. Badiee, S. Otroj, Non-cement refractory castables containing nano-silica: performance, microstructure, properties, Ceramics- Silikaty 53 (4) (2009) 297–302.

[10] C. Parr, C. W ¨ ohrmeyer, The advantages of calcium aluminate cement as a castable bonding system, in: Proceedings of St Louis Section Meeting of American Ceramic Society, USA (2006) pp. 20.

[11] M.A.L. Braulio, C. Tontrup, J. Medeiros, V.C. Pandolfelli, Colloidal alumina as a refractory binder, in: Proceedings of 35th Alafar congress, Lima, Peru (2010) pp. 10.

[12] S. Ghosh, R. Majumdar, B.K. Sinhamahapatra, R.N. Nandy, M. Mukherjee, S. Mukhopadhyay, Microstructures of refractory castables prepared with sol–gel additives, Ceramics International 29 (2003) 671–677.

[13] Biswas, Subir, and Debasish Sarkar. Introduction to Refractories for Iron-and Steelmaking. Cham, Switzerland: Springer International Publishing, 2020.

[14] A. M. Hundere, B. Myhre and B. Sandberg, "Mullite Bonded Castables," Proceedings of the International Symposium on Refractories, Haikon, China, 12-15, November 1996.

[15] Singh, A. K., & Sarkar, R. (2015). Synthesis and characterization of alumina sol and its use as binder in no cement high-alumina refractory castables. International Journal of Applied Ceramic Technology, 12, E54-E60.

Refractory design developments & application for stoves of blast furnaces in SAIL plants

Surendra Prasad, A.C.Goyal, A.Dewangan, T.C.Joshi & S.Manna
Centre for Engineering and Technology, SAIL, Ranchi

Abstract
Stoves used in the world up to the end of the 1960's were primarily based on the use of material to withstand temperature. Little attention was paid to the movement of Refractory lining within the stove while designing. It was an accepted fact that stove repairs would be required every time the Blast Furnace goes down for major repair.

Steel companies throughout the world were eager to improve furnace efficiency and reduce coke rates. One of the key areas to achieve lower coke rates is "Higher Hot Blast Temperature" from the stoves. This in turn not only required improved refractory quality but also improvements in the construction design.

In the present market scenario, there is a continuous pressure to lower production costs in the steel industry. Therefore any reduction in the production cost of hot metal contributes significantly to the cost indices of the company.

Introduction

Hot blast stove is an integral part of blast furnace complex and contributes significantly towards blast furnace productivity and cost effectiveness. In general, every 100^{o}C rise in hot blast temperature contributes to ~1.75 % increase in production and a reduction in coke rate by 12 to 24 kg per ton of hot metal. Thus increase in hot blast temperature will not only help to increase output but also reduce production cost from existing blast furnaces. This emphasises the need for up-gradation of existing stoves which were generally designed to give hot blast temperature of 850 ^{o}C to 900 ^{o}C
This paper deals in "An approach to refractory design developments and application for stoves of blast furnaces in SAIL plants".

STOVE DESIGN CONSIDERATION

In hot blast stoves, heat transfer at the brick-interface is the main process, which takes place from the outgoing combustion products to checker work and in the reverse cycle from checker work to the cold blast. The amount of heat transferred per unit of surface depends on the following factors:

- Velocity of the gases
- Conductivity of brick work
- Shape and roughness of surface
- Temperature differences between brick surface and gases
- Heat capacity of the refractory material

A number of factors need to be taken into consideration while designing new stoves or upgrading an existing stove system. Such factors are:

- Number of stoves and mode of operation i.e. cyclic/parallel/staggered parallel
- Duty requirements i.e. hot blast temperature (HBT) & hot blast volume (HBV)
- Stove cycle time i.e. gas & blast periods
- Fuel and fuel enrichment
- Space considerations i.e. height versus diameter
- Pressure losses
- Efficiency

An optimal stove design is a trade-off between the above requirements and cost considerations.

Experience of the designer also plays a vital role in generating an optimum stove design.

STOVE DESIGN

The common causes for poor stove performance can generally be attributed to one or more of the under mentioned reasons:

- Bending of partition wall due to non-uniform expansion of the wall and cross-leakage through the gap created due to cracking of the wall.
- Localised overheating of the partition wall due to flame impingement by mechanical burner causing thermal stress, crack formation and short-circuiting in the wall.
- Chocking of checker holes in the upper part due to reaction of checker brickwork with the dust particles especially if back drafting is done through stoves.
- Failure of dome due to non-uniform movement of the supporting wall or inadequate expansion.
- Deformation of checker support system.
- Hot spot on the shell
- Sinking of filling material in combustion chamber

An approach to stove design not only looks to eliminating the above problems but also aims for campaign life of over 20-years by carefully reducing both mechanical and thermal stresses on refractory through improved refractory design and material selection.

REFRACTORY DESIGN DEVELOPMENT

There are no standard modules of stove design. Each stove system is tailor made based on the duty requirements, space considerations and available infrastructure facilities. During up-gradation of existing stoves important considerations are shutdown time available, method of implementation i.e. phased or at a time modification of all the stoves and cost. This calls for retaining the existing stove shell, maintaining level of various openings, level of automation, etc.

The salient features of an **improved stove refractory design developments** are as under:

- Improved shell safety lining construction
- Improved wall construction
- Improved partition wall construction
- Improved dome construction
- Improved expansion & sliding joint construction
- Improved checker design construction
- Improved ceramic burner construction

Improved Shell Safety Lining Construction

For minimising the stove shell temperature, it is necessary to optimise safety lining thickness with better insulating material while designing the stove. The earlier safety wall construction utilises mica crumb insulating materials with expansion absorbing properties. However, during course of operation, mica crumb settles down and localised hot spot were developed. Later on use of different quality of insulation materials like insulation slab or ceramic board of adequate thickness were used at different elevations of the stoves to ensure shell temperatures preferably below 100^{o}C. This material was found better w.r.t. mica crumb but in long period it is observed that insulation slab/ ceramic board also loose it's strength and get crushed, causing localised hot spot.

The recent development to overcome above shortcoming has been carried out by reputed designers and it has been established to use gunning material with suitable anchoring arrangement. It gives better performance compared to mica crumb or insulation slab or ceramic board.

Improved Wall Construction

For maximising the checker chamber area, it is necessary to optimise the lining thickness while maintaining lower shell temperatures. The present wall construction utilises stronger insulating materials with better insulating properties. Different qualities and thickness of insulations are used at different elevations of the stoves to ensure shell temperatures preferably below 100°C.

Extreme care is to be taken to ensure that the vertical expansion along the height of the load bearing walls in both checker and combustion chamber is matched. Also to take care of undulations of the bottom plate and ensure a horizontal surface for starting all the walls, a levelling layer of fireclay castable is preferred.

Use of tongue & groove bricks in walls and top 120° arc of the openings ensures better stability. Use of special shaped bricks is preferred for ease of construction with staggering of joints and inter-locking of different walls.

Improved Partition Wall Construction

In an internal combustion chamber stove, partition wall is the most critical part of refractory construction. In the conventional double layer partition wall, a number of cracks develop due to thermal stresses and differential movement of the two dense layers. This leads to short-circuiting. Short-circuit reduces the thermal capacity of the stove, damages the checker work, reduces efficiency and affects the structural stability of the wall.

The modified partition wall consists of layers, which can move, freely in vertical and horizontal directions by the application of sliding and expansion joint. Between the dense layers, intermediate insulation layers are provided to reduce the thermal gradient. This reduces both thermal stresses and the bending tendency of the wall towards the checker work. To improve gas tightness and eliminate short-circuiting, heat resistant steel alloy sheet is incorporated at the cold face of the partition wall behind the dense layer on checker chamber side.

Improved Dome Construction

The hemispherical dome construction is not very stable at higher hot blast temperatures. Parabolic dome provides stable configuration, which minimises the slipping of the dome brick work at high temperatures. For higher stove diameter i.e. above 9 meters, mushroom type dome is preferred. Mushroom dome design requires greater centre-to-centre distance between the stoves. When installation is done in existing steel shell, a parabolic dome is preferred since it is free of bending stresses and stability is better.

The parabolic dome consists of two layers. Dense layer of silica/ alumina bricks with tongue & groove construction and suitable expansion joints. Over the dense layer, an insulation layer is provided. One extra layer of insulation refractory is glued directly to the steel shell. In between the steel shell and dome lining, gap is kept for free movement of the dome lining as a whole.

Latest development is to use mushroom dome construction for better stability of dome as well as independent expansion of walls & dome.

Improved Expansion & Sliding Joints Construction

In earlier stove design, there was no provision of expansion as well as sliding joints. Mica crumb was used adjacent to the shell to absorb all expansion of the brick work. Due to thermal stresses and difference in movement of different layers and sections of refractory lining, cracks develop in the lining causing hot spots and pre-mature failure.

Present refractory lining is designed with expansion joints of different thickness in different thermal zones. The provision of expansion joints is made on the basis of accurate calculations, which can accommodate the total expansion of the brickwork. The expansion joints are designed to avoid straight joints and are packed with flexible refractory fibres like ceramic felt or ceramic wool.

Sliding joints are provided so that entire panel of brickwork can move independently without affecting the adjacent brickwork. This way formation of internal cracks due to stress development in the brickwork can be prevented.

Improved Checkers Design Construction

In order to limit the stove size, it is imperative to increase the heating surface of the stove. Various checker shapes with specific heating surface, varying from 20 to over 50m^2/ m^3, are being used in stoves. The existing trend is to use hexagonal checkers with cylindrical openings for maximising the specific heating surface area. The hexagonal checkers are laid dry, have provision to take-up horizontal expansion and are very simple to install. Based on design dome temperature and waste gas temperature, the height of different quality of checker is determined according to their maximum service temperature. In case, silica checkers are used the design interface temperature should not drop below 750 ^{o}C at any point of operation.

The refractory supporting system is specific to the checker brick design. The main consideration in designing checker supporting system is the avoidance of deformation under load and temperature. For this reason, a heat resistant alloy cast iron construction is selected, which has the advantage of little deformation under load and no residual stresses during manufacturing process.

Table-1

SN	Description	Unit	Type of Checkers			
			T-1	**T-2**	**T-3**	**T-4**
1	Specific Heating Surface	m^2/ m^3	24.01	31.75	42.10	50
2	Heating Surface Area per Stove	m^2	27, 114	38, 855	47,430	56, 450
3	Gas Volume	Nm^3/hr	40, 628	39, 371	39,182	38, 872
4	Air Volume	Nm^3/hr	35, 980	34,874	34,718	34, 556
5	Waste Gas Temp	^{o}C	302	258	255	249
6	Efficiency	%	78.98	81.5	81.89	82.78
7	Fuel Cost/ year	Rs Cr	262.1	254.0	252.8	251.2
8	Savings w.r.t. Type-1	%	0	3.1	3.55	4.2

Note: Cost of fuel has been taken as ~ Rs 1000/Gcal and stove operating hours as 8400 per annum

To emphasise the effect of different checker shapes on stove performance, calculations have been carried out using off-line mathematical model for a 3-stove system operating in cyclic mode and suitable for HBT of 1100^{o}C and HBV of 2600 Nm^3/min. The outcome of the calculations is given in **Table-1**.

From the above Table, it is clear that there is considerable benefit in fuel saving over a stove campaign.

Other benefits of use of high efficiency checker are reduction in size of stove resulting less refractory and less steel and finally low cost.

Improved Ceramic Burner Construction

Internal vertical ceramic burner is preferred over the external horizontal mechanical burner, which has lower thermal efficiency and tendency to damage the partition wall. In ceramic burners, equal distribution of gas and air at burner tip can be obtained which improves combustion efficiency and flame stability. The main advantages of ceramic burner are:

- Good and stable combustion for any air/ gas ratio giving very high combustion efficiency.
- Due to vertical flame in the centre of the combustion chamber, a good temperature distribution both across length and cross-section of the combustion chamber can be achieved. This minimises thermal stresses in the stove refractories construction.
- Elimination of hot spot which appears on the lower partition wall when using a mechanical burner.
- Elimination of maintenance problems on the burner door, since no burner door is required.
- No maintenance of ceramic burner is necessary.
- Low carbon & nitrogen emmission

However, while upgrading an existing stove it is not always feasible to accommodate ceramic burner without major modifications or compromising on duty requirements.

Recent development is use of improved design multi-slot ceramic burner for better stability, combustion and efficiency.
Sketch of a typical stove cross-section with mushroom dome & ceramic burner is enclosed.

REFRACTORY MATERIAL DEVELOPMENT

The aspects, which will influence the selection of different qualities of refractory materials for the working layer, are as under:

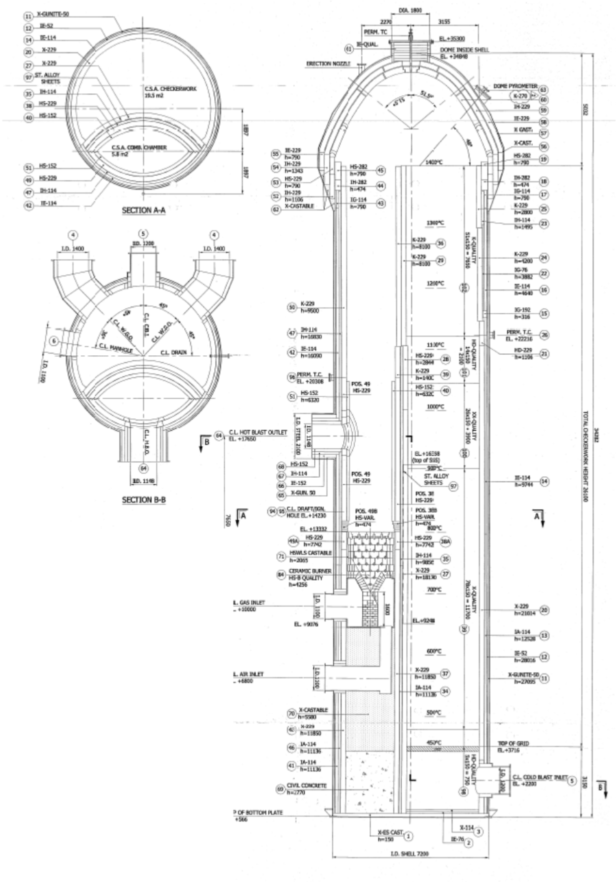
- Thermal expansion
- Spalling resistance
- Bulk density (heat capacity & conductivity)
- Chemical resistance
- Cost

There is a wide difference of opinions on the use of silica compared to high alumina & magnesite refractories. The main technical advantages of silica are the excellent spalling resistance in combination with volume stability at temperatures above 600°C. The disadvantages are lower heat capacity at all temperatures and poor spalling resistance between 100 and 300°C. Accordingly, it requires careful heating up and cooling down. Magnesite has the advantage of high heat capacity but with poor spalling resistance. High alumina has high heat capacity together with good spalling resistance at all temperatures. **Table-2** gives a comparison of properties of these 3 materials.
From the Table it is clear that for those parts where during normal operation temperatures will not be lower than 600°C Silica is an ideal material. There will be no movement in the construction notwithstanding the continuous cyclic movements during gas & blast period. Another advantage of silica observed after years of operation in stoves through which back drafting was usual, is the glazing effect of the

Table –2

Property	**Unit**	**Material**		
		Silica	**Magnesite**	**High Alumina**
Thermal Expansion • 0–300 °C • 300–600 °C • 600–1500 °C	 % % %	 1.1-1.2 0.1-0.2 0.0-0.2	 0.35 0.4 1.8	 0.1-0.2 0.1-0.2 0.4-0.6
Spalling Resistance • 0–300 °C • 300–600 °C • 600–1500 °C	-	 V/Poor Good Excel	 Poor Poor Poor	 Good Good Good
Bulk Density	gm/ cm^3	1.8	2.5-2.6	3.0
Heat capacity	-	Low	Very High	High
Chemical Resistance	-	Very Good	Good	Good
Dust built on top Checkers	-	None	Small	Cauliflower formation

walls and checker work without any damage to the structure and choking of openings. Accordingly, it is preferred to use silica in dome, courses of walls and upper checker work. While upgrading existing stoves, in case of limitation of checker volume, the application of high alumina or magnesite would be an alternative. Magnesite is generally not used because of poor spalling resistance. In lower combustion chamber the only alternative is use of fireclay/ high alumina bricks.
As back up layers fireclay and mica based insulation materials or porosent materials are selected depending on safe working temperature, thermal conductivity and strength. Against the shell use gunning material is preferred because of low thermal conductivity, ease of installation, strength and longer life.
Now a days to get a long and uninterrupted service life, most modern plants demand better quality refractories and in the material specification properties like creep, HMOR, thermal conductivity are also specified.



CONCLUSION

SAIL has over 57 Nos. of hot blast stoves of various designs. Out of these, only 36 nos. of stoves have silica refractories in dome, checkers and walls. Considering the operating discipline required and temperature duty for silica stoves, subsequently modified stoves were designed with high alumina refractories. In line with the design considerations enumerated above CET has modified around 29 stoves within SAIL and outside.

The thrust in the coming years should be to get the maximum out of the existing stoves through design modifications, material selection, standardisation of material specifications and better stove operation with minimal investments for temperature up to 1200 ^{o}C.

Cost effective refractory handling manipulator for safe & better ergonomics

Gaurav Pandey*, Suchit Kumar Mahanta, Gautam Kr. Choudhary, S. Paul, Ujjwal Kumar, Deepak Kumar, Hiroshi Nagata, Sunanda Sengupta, P.B Panda, **Navneet Sinha, **Rajeev Ranjan

**TRL Krosaki Refractories Ltd.. **Tata Steel Ltd.*

Abstract

During ladle preparation at tilter, time involved plays a crucial role in shop productivity. In ladle preparation, slide gate refractory changing is a time taking & exhaustive process as it involves changing of refractories like upper nozzle, slide plate & lower nozzle. Changing of these refractories is human exhaustive process as these are heavy in weight and executed in heat & dusty environment and the entire process is done manually in every steel plant of India.

Refractory arrangement in slide gate system is in such a way that firstly upper nozzle is fixed in ladle well block (it is part of ladle lining) then slide plate and lower nozzle. One of the highly exhaustive processes is changing and fixing of upper nozzle its weight is around 17 Kgs and after applying mortar its weight increases to 25-30 Kgs and operator has to lift and fix manually. Upper nozzle fixing process requires more time, human effort leading to fatigue to operators and sometimes delay in preparation of ladle. This is a controlled and precise operation, deviations can lead to failure. To eliminate these problems a mechanized manipulator was designed to reduce the human effort, better ergonomics and to make the process more easier and operator friendly. This mechanized manipulator consists of some mechanical & pneumatic components which allows operator to lift and handle such heavy load without any effort. Manipulator is provided with an air balancing system which carries the load of refractory which helps in lifting and fixing of nozzle with all degree of freedom. This system works completely with pneumatic, with this system operator has to give only 1-2 kgs of force for lifting 25-30 kgs of load as complete load is being nullified by the air balancing system. A special type of gripper was also provided to grip the refractory components without damaging it. This type of system can be seen in automobile and other industries for handling load but for steel plants this was a bit challenging task as in steel plant there are lot of constraints like heat, dust, area etc. This type of solution can serve to solve various weight handling issues across steel industry.

Keywords: Nozzle fixing, Manipulator, Mechanization

INTRODUCTION

In steel making process various process are being carried out from primary steelmaking to final casting of steel show in fig.1 and in this process liquid steel is carried in steel ladle. First ladle is sent for tapping to BOF (Basic oxygen furnace) where the processed liquid steel is poured into the ladle and then ladle is sent for secondary refining station and then casting shown in fig.2 where the casting is done by opening of ladle slide gate machine which is mounted underneath of steel ladle and actuated with the help of hydraulic cylinder. After operating of slide gate machine, the bore of the slide plate inside the machine gets matched and casting starts. In the whole process of steelmaking ladle slide gate plays a very crucial role for casting of steel smoothly.

Fig. 1 Steel making process

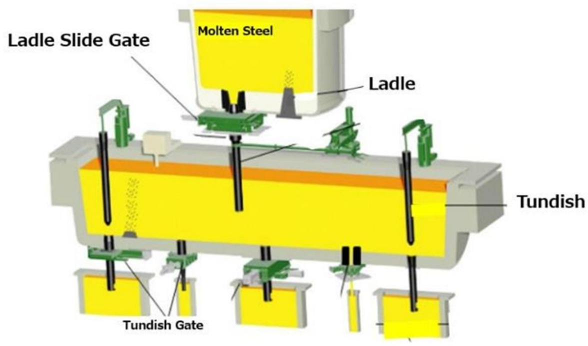


Fig. 2 Steel casting process

Ladle slide gate machine shown in fig.3 consist of various consumable refractories like

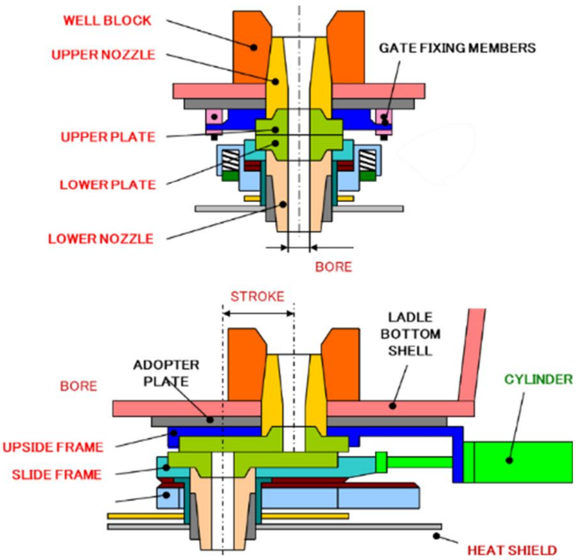


Fig. 3 Slide gate machine assembly

slide plate, upper nozzle, lower nozzle. After casting is completed, ladle is sent to preparation area also known as ladle tilters to make the slide gate ready by cleaning the hole and changing the slide gate refractories if required. The entire process of slide gate preparation and refractory changing is done manually almost in every steel plant in India and world as well.

CHALLENGE IN FIXING UPPER NOZZLE

Slide gate preparation job is done manually almost in every steel plant of India and world. During preparation of slide gate its refractories like upper nozzle, slide plates & lower nozzle is changed depending upon its life. These refractories are heavy in weight specially upper nozzle. It weighs around 17 kgs and refractory arrangement in slide gate system is in such a way that first upper nozzle is fixed in well block (it's a part of ladle lining) and before fixing upper nozzle into well block a thick mortar coating is applied over the outer surface of upper nozzle as a joint material between upper nozzle and well block and it is lifted by the help of jig for fixing into well block shown in fig.4. In total its weight reaches upto 30 kgs approx. then slide plates and lower

Fig. 4 Manual upper nozzle fixing process

nozzle is fixed which is later tightened by mechanical force.

Associated problems-

Fatigue to Operators - The entire process is done manually like lifting & fixing heavy weight and done in heat & dusty environment which makes the process more human exhaustive as its done multiple times (normally 10-12 in a day).

Chances of Error – As its done manually and the process requires precision in upper nozzle fixing, any deviation could lead to leakage of liquid steel.

Delay in preparation- Due to manual preparation and sometimes human error preparation gets delayed and delay in slide gate prepration directly effects the shop production as delay in ladle supply causes waiting of BOF.

Challenge was taken to develop a mechanized system to solve the issues with manual process and to make the operators work easier.

AVAILABLE OPTIONS

Robotic System- This system includes advanced robots and the entire process is done

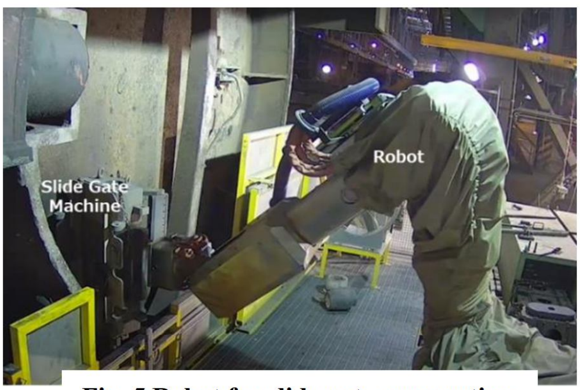


Fig. 5 Robot for slide gate preparation

fully automatically with robots as shown in fig.5. Only few steelmakers outside India has installed the system which is still under development stage.

As this include advanced systems and requires high maintenance so it also requires very high capital cost.

Available manipulator in market- Available manipulator system which helps in lifting heavy refractories but the cost of this manipulator is very high compared to the manipulator covered in this paper.

SEMI-MECHANIZED MANIPULATOR

The above mentioned options doesn't turned out to be the feasible options as the cost involved was very high. So it was decided to built inhouse semi- mechanized manipulator. The objective of design was to make a manipultor which will easily lift the heavy weight of refractories and will work in such a challenging environment at optimum cost.

Manipulators weight lifting concept is based on air balancing system, this type of lifting devices are normallly used in automotive industires but using same in steel industry was a bit challenging due to its working environment (Hot & dusty). Using air balancing concept a semi-mechanized manipulator fully pneumatic based system was designed as shown in fig.6.

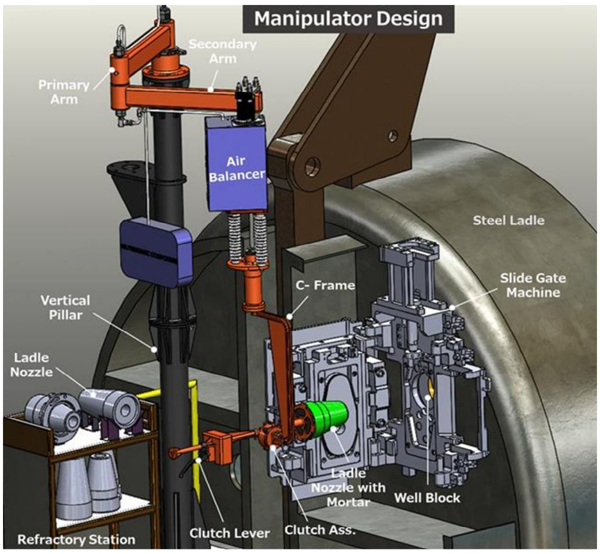


Fig. 6 TRLK Semi-mechanized manipulator

This Manipulator mainly consist of vertical pillar, primary arm, secondary arm, air balancer, clutch, gripper and other parts.

Vertical Pillar- Provide strength and holds the load of system it is mounted in the tilter platform.

Arms- Provide degree of freedom and movement to system so that upper nozzle can be moved within the range.

Air Balancer- Lifts and balance the load with pneumatic cylinder operator only need to give 1-2 Kgs of force to lift 25-30 Kgs of load. This air balancer can lift upto 100 Kgs of load.

Clutch- Provides rotary provision for upper nozzle with the help of incorporated jig with very simple clutch mechanism.

Gripper- Grips the upper nozzle from inside by pneumatic force without damaging and works in High temperature.

The whole system (Air balancer & gripper) works with pneumatic line with minimum required pressure of 5 bars. Operator only needs to guide the upper nozzle for fixing & applying Mortar as load of upper nozzle is being nullified by the air balancer shown in fig.7. For applying mortar rotary provision is also provided in the jig as shown in fig.8.

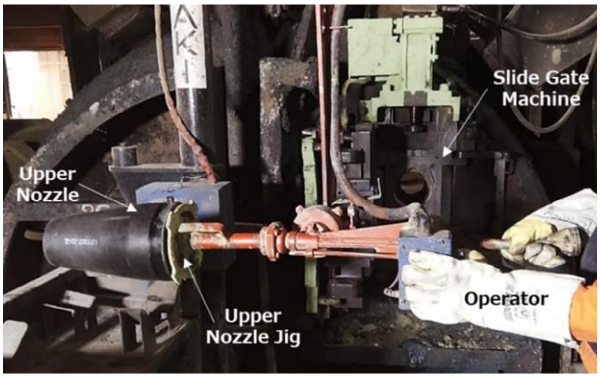


Fig. 7 Lifting & balancing of upper nozzle weight

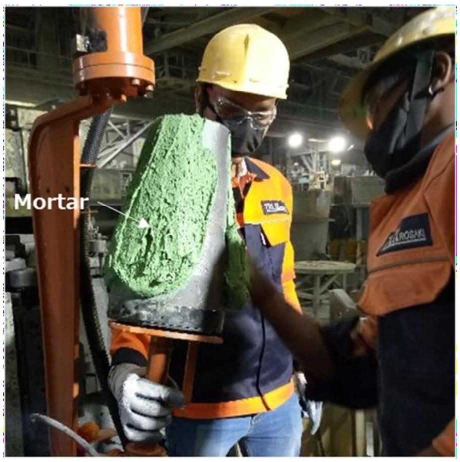


Fig. 8 Applying mortar on upper nozzle

ROADBLOCKS

Various challenges were encountered during development & execution stage. Each challenge was mitigated as explained-

Selection of Refractory Gripper- As upper nozzle is a refractory item so conventional/mechanical grippers can't be used as it can damage refractory and light gripper could get burn at high temperatures as during upper nozzle fixing well block temperature is very high. So silicon based gripper was used for gripping upper nozzle as shown in fig.9 from inside as this material can resist high temp. (upto 400^0C) without damaging refractory. After giving pneumatic pressure it get inflates and grips the upper nozzle.

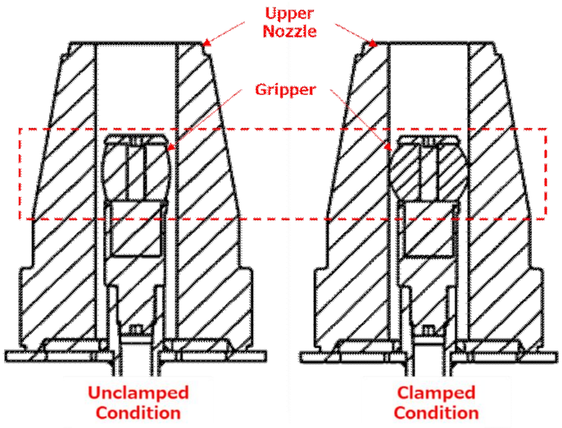


Fig. 9 Refractory gripper design

Working Environment- The slide gate preparation area is dusty and all the operations are done in high temterature area so the selection of parts were done in such a way so it can sustain in that environment. All pneumatic circuit were provided with proper covering with high temp. resistant covers, bearing with high temp. and dust proof seals.

Space contraints- Slide gate preparation area has very less space and 2-3 operators works in the same platform there was chances of hinderence to operators in working and visibility. So flexible arrangement was provided in the manipulator. While use only its arms to opened else it will be parked in its parking position without causing any hinderence.

Peoples acceptance- As the upper nozzle fixing process is manual since the inception of steel plants and still most of the steel makers in India and world still follows the same practice. It was difficult for Operators to adapt & accept new practise as they weren't familiar with any kind of mechanization for the process. So proper training and awareness were provided to operators.

Optimizing Cost- It was necessary to optmize the cost as it was the main reason for not going with the availbale options. So the whole system was designed and built in India. Desing was kept simple with less delicate items.

CONCLUSION

Due to manual operation the whole process becomes human exhaustive as refractories are heavy in weight and the entire process is done in hot & dusty area. It is important to improve saftey of workers. Some advanced automation like robotics has been installed in few plants outside of India but the initial cost required is very high and it is still in development stage.

Semi-mechanized manipulator helps operator to lift the heavy weight of refractories with very less effort. To lift 30 kgs of load operator only needs to give 1-2 kgs of force as the load is being nullified by the system. Ealier the whole load was lifted by two operators as shown in fig.10.

Fig. 10 Fixing of upper nozzle manual & mechanized way

Effort required is now reduced to 98% with precise control. Process has become more standard now as load is lifted by the system operator only needs to guide and push the jig into well block in order to fix upper nozzle which also take less time. With this semi-mechanized system process has became smoother & safer.

This Manipulator was designed and built in India with very optimum cost. It can be customized easliy and can be used as lifting & handling applications (upto 100 Kgs of load) across steel plant and other industries.

REFRENCES

1. The Making of Iron & Steel – SEAISI (Pg. 32 – 35)
2. Making, Shaping & Treating of Steel, 11th Ed., A Cramb, ed., AISE Found., 2000, Chapter 4.3
3. Human-Centered Robotic Development in the Steel Shop: Improving Health, Safety and Digital Skills at the Workplace- STEEL 2021 Page- 9

Study on Recycling of Used Mag-Carbon Brick in production of Mag carbon Bricks

Pallavi Singh, Sandeep Srivastava, Amit Charit, Anjali Bharti
SAIL Refractory Unit, Bhilai, SAIL
email id: Pallavisingh.nikki@gmail.com

Abstract:
Mag-Carbon bricks are extensively used in steel ladle, converters, VAD vessel and EAF as working lining. After the campaign of the refractory lining is completed, approx. 30-35% of the working lining is dismantled which is of no use to the steel makers. In congruence with the zero waste management principle and also keeping in view the scarcity of the virgin materials, study has been conducted for recycling of these used Mag-Carbon bricks as grog for manufacturing of Mag Carbon bricks. The study reveals that used Magnesia Carbon Bricks may be used in making fresh bricks in both calcined and non-calcined form for replacement of virgin raw material to a certain extent, without any adverse effect on the end properties of the bricks. Moreover, recycling of Magnesia and Carbon saves the energy required to produce it. This study enabled us to reduce the cost of production of Magnesia Carbon Bricks thus reducing the specific cost of refractory in steel making, but without compromising on the quality of the Magnesia Carbon Bricks.

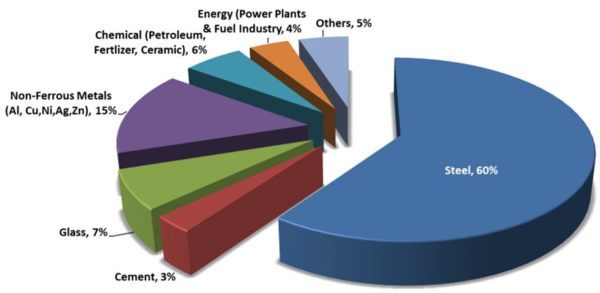
1. INTRODUCTION

One of the oldest technical texts in the history of mining and metallurgy, De Re Metallica (by Agricola, G.,1556), list ore, fuel and refractory materials including heat insulators, as the three substances essential for metal refining. All through the Iron Age from ancient times up to now, refractory hasbeen closely engages in iron and steel making contributing to human civilization. Refractory in itself is a huge subject of research and studies. However we want to limit ourselves to the refractory bricks used in secondary steel making processes, specifically to Magnesia carbon bricks. High purity Magnesia is the major base material for MCB as it has high melting point of 2800^{o}C.Different types of magnesia are available based on their origin and process of manufacturing. Depending on the application, different types of magnesia are judiciously chosen.

2. CHARACTERISTICS OF REFRACTORIES

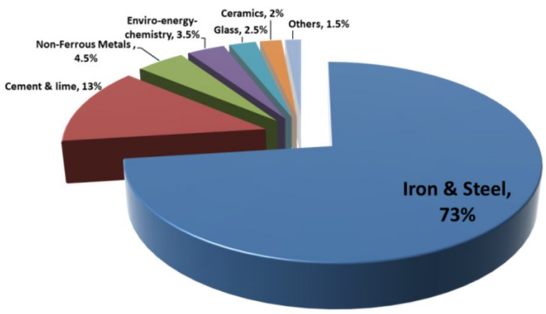
1. Should be Infusible at operating temperature
2. Should be chemically inert towards corrosive gases, liquids etc.
3. Should not suffer change in size at operating temp
4. Should have high refractoriness.
5. Should have high load bearing capacity at operating temp.

2.1 Global Refractory consumption Pattern: Sector Wise



Source – Roskill Information Services

2.2 Indian Refractory consumption Pattern: Sector Wise



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3. MAGNESIA-CARBON REFRACTORIES

In this paper, we have focussed our studies around magnesia carbon refractories. MgO-C bricks are used extensively in steel making processes especially in basic oxygen furnaces, electric arc furnaces, lining of steel ladles, etc.The evolution and use of magnesia refractories in combination with carbon started in the early 1950's with pitch bonded dolomite refractories, developed primarily for the basic oxygen furnace.Thereafter magnesia fines were used in conjunction with the dolomite coarse fractions bonded with pitch. Further improvements came with the all magnesia pitch bonded brick. In the 1970's the burnt and impregnated magnesia brick with finite pore size became the standard for the charge pad and other high wear areas, starting the beginning of the zoned lining for basic oxygen furnaces. About that time magnesia purity became a factor and a special low boron 96% magnesia grain having a lime to silica ratio of 2 to 3:1 was used extensively.The 1980's saw the development of resin bonded magnesia-graphite, first with higher carbon content and then with the addition of antioxidants to preserve the carbon content.

MgO-C brick is a composite material based on MgO and C and bonded with high carbon containing pitch and resin, with some metallic powder as anti- oxidants to protect the carbon. These bricks show excellent resistance to thermal shock and slag corrosion at elevated temperatures. MgO-C bricks have dominated the slag line of ladles as they possess superior slag penetration resistance and excellent thermal shock resistance at elevated temperature because of the non- wetting properties of carbon (graphite) with slag, high thermal conductivity, low thermal expansion and high toughness.

4. RAW MATERIALS FOR MgO-C BRICKS

Typical constituent raw materials of MgO-C bricks are outlined below.

4.1 Magnesia

The main raw materials for the production of MgO-C refractories are sintered or fused magnesia and flake graphite. Natural magnesite ($MgCO_3$) deposits are the main source of magnesia; other sources are seawater and brines.

Magnesia content is around 80 % or more of the total batch. Three different types of magnesia raw materials are used to produce MgO-C brick. Based on the origin Magnesia are classified as:

(i) Dead Burnt Magnesite: Natural deposit of Raw Magnesite ($MgCO_3$) is first beneficiated then calcined, followed by high temperature firing, to produce Dead Burnt Magnesia.This material contains negligible amount of Boron with high lime silica ratio.

(ii) Sea Water Magnesia: This is produced by extraction of Magnesium Chloride salt from sea water followed by beneficiation, calcination and high temperature firing. This material is very pure with cryptocrystallinestructure and has high $CaO:SiO_2$ ratio.

(iii) Fused Magnesia: This is produced by fusion of Raw Magnesite or Calcined magnesia by means of electric arcing and cooled down to crystallization.It has advantages of high purity and large crystal size. Thermal shock resistance is poor for this material.

The purity, crystal size, grain boundary, flux, lime / silica ratio, and other properties of the magnesia aggregate affect the corrosion resistance of MgO-C bricks.

4.2 Graphite

In MgO-C brick, carbon plays a very important role by providing non-wetting property to the refractory. Graphite is used as the carbon source since it shows the highest oxidation resistance among different commercial sources of carbon. Due to the flaky nature of graphite, it imparts higher thermal conductivity and lower thermal expansion, resulting in very high thermal shock resistance. Purity of graphite is also an important factor. Impurities react with MgO and form low melting phase which results in lower corrosion resistance and also lower hot strength. The role of graphite in MgO-C bricks can be summarized as

(i) It prevents the slag penetration into the brick due to the high wetting angle between slag and graphite,

(ii) It improves the thermo – mechanical properties and spalling resistance of the bricks.

Theflake size of graphite has also a great role in improving the abrasion, corrosion, and oxidation resistance of MgO-C bricks. Natural flake graphite is normally used for MgO-C bricks.

4.3 Resins

Resin is found to be the best binder for MgO-C refractories because of its properties such as

(i) it contains high quantity of fixed carbon which gives strong bonding property,

(ii) it possesses high dry strength because of its thermosetting nature,

(iii) it produces less hazardous gas than tar / pitch,

(iv) at curing temperature (around $200^{O}C$), it polymerizes which gives isotropic interlocking structure, and

(v) cold crushing strength (CCS) increases with the increase of resin content.

(vi) Crosslinking of PF resin occurs during curing of the bricks.After the end of the curing step and before firing, the resin is responsible for keeping the ceramic particles packed and maintaining the integrity of the overall structure.

Phenolic resin is normally used as binder for magnesia aggregate, graphite, and other raw materials in MgO-C bricks. Phenolic resin comes in two types namely the thermosetting ‘resol’ type and ‘novolac’ type.

4.4 Other additives

Carbon components contained in MgO-C bricks are oxidized by oxygen and carbon dioxide in the atmosphere or by iron oxide in the slag. Antioxidants such as metallic powders are added mainly to suppress this oxidation.

5. MAGNESIA IN INDIAN REFRACTORIES

India is not blessed with high purity magnesiaand is found in Salem and Almora region. As Indian magnesite generally contains high silica or high iron, thus are not recommended for use in high vulnerable areas. Hence the high purity magnesia, which is required for the production of MgO-C bricks are imported from other countries like Japan, Turkey, Australia, and Netherlands. While importing high purity magnesia, we face following challenges.

5.1 Challenges faced globally

The Refractory Industry that consumes magnesite to a large extent is experiencing a range of challenges.

1. Geo political issues: Russian invasion of Ukraine in Feb 2022 has resulted in chaos in the global natural gas, coal, oil and electricity markets.Prices of natural gases, electricity have reached stratospheric levels, adding extra cost on production of magnesia.
2. Economic issues: The outbreak of covid pandemic in 2020 has virtually led every major economy into prolonged lock-downs. Strict lockdown measures, supply chain disruptions, fewer labor options, and limited mining activities considerably impacted the magnesia production.
3. Volatility in Freight rates:Sea Freight rates are constantly changing. With rates fluctuating by up to 50%, we have to face the problem of dynamic pricing.
4. Environment and carbon emission: Magnesia is an important connecting link between magnesite and refractory. Magnesia production is an energy intensive process. The carbon emitted from magnesia production is directly caused by carbonate decomposition and fossil fuel combustion.The major gaseous pollutants include CO2, SO2, NOx, CH4, HF causing global warming and acidification.

Due to the aforesaid factors, problems faced by Indian refractories while importing Raw materials from other countries are as follows:

1. Due to the aforesaid reasons, the lead time of availibilty of magnesia has increased.
2. There is always a risk of uncertainty in the availability of magnesia while importing.
3. The fluctuation in prices of raw materials and freight charges affects our cost of production.

6. NEED OF THE HOUR

The raw material i.e. high purity magnesia is expensive and its natural deposits of are running out rapidly. On the other hand the bricks made out of themare consumables. Hence sustainable use of these bricks is the need of the hour. In general, left over bricks i.e. the used bricks with left over thickness after the completion of the vessel life, do not have much value. This also creates disposal issues of the bricks. To overcome these issues, recycled refractories have been taken into consideration during recent years.

Large quantities of used refractories are generated by the steel industry annually. The recycling of the used refractories is currently gaining in importance for both economic and ecological reasons, such as increased prices for raw materials, dependence on raw material supplies, and the need to reduce CO_2 emissions and energy consumption. Recycled MgO-C refractories are used for as slag conditioners in electric arc furnaces. However, the highest benefit can be achieved when they are used as secondary raw materials for the production of refractories.This is required for sustainability of nature and life.

7. EXPERIMENTATION PROCEDURE:

7.1 The left over bricks, henceforth which will be said as grog, were collected from Bhilai Steel Plant and were brought to SAIL Refractory Unit, Bhilai.

7.2 Chemical analysis of the grog was done at the laboratory mainly for the constituent's viz. %C and %MgO.

Type of grog	%C	%MgO
Normal Grog	8-10	80-85
Calcined Grog	0.5-1	89-93

7.3 Theoretical approach: This development work was based on the following assumption:

- Resistance of graphite increases monotonically with increasing temperature up to 3000 °C. Hence the carbon present in the leftover thickness should be unused.
- Melting point of magnesia is also high, hence the MgO present in the left over thickness remains untapped.
- However the impurities such as Fe_2O_3, CaO, SiO_2 increases due to the interaction with slag and metal.

7.4 Al_2O_3 from Aluminium powder combines with MgO at higher temperature to form Magnesium Aluminate spinel $MgAl_2O_4$. Magnesium aluminate spinel is an excellent refractory material with high melting temperature and thermal conductivity. Hence the presence of this spinel in grog may help us in getting better refractory properties.

7.5 Sample preparation:

- The metal and slag sticking on the bricks were removed from the grog.
- The grog was then crushed to the desired size fractions.
- Two types of grog were taken for the study. One in as it is form i.e. known as normal grog and the other after calcination known as calcined grog.
- A total of 8 trials were done with the following composition, keeping all the other parameters same:

Trial name	Type of grog
C1	Without grog
C2	Without grog
C3	Normal grog
C4	Normal grog
C5	Calcined grog
C6	Calcined grog
C7	Normal grog + calcined grog
C8	Normal grog + calcined grog

8. RESULTS AND ANALYSIS

The above samples were tested for their physical and chemical properties. Chemical composition wise they were almost similar. However the physical properties were tabulated as given below:

Trial	AP	BD	CCS	COKE AP	COKE BD	COKE CCS	HMOR
C1	4.2	2.95	415	12.1	2.85	212.9	43.3
C2	4.3	2.92	350	13.7	2.98	237.1	65.4
C3	4.25	2.95	360	12.5	2.92	186.7	37.5
C4	4.3	2.93	315	12.1	2.88	220	58
C5	4.05	2.99	422	10.9	2.93	179.4	48.3
C6	4.35	2.94	322	10.4	2.91	187.3	61.9
C7	4.25	2.95	410	11.5	2.95	181.7	47.2
C8	4.05	3.0	387	11.4	2.85	205.2	78.7

9. CONCLUSION

From the above study, it may be concluded that used MgO-C brick, if judiciously used, either in calcined or normal form, can be a partial substitute of virgin raw material for manufacturing of MgO-C bricks. Apart from the direct tangible benefits obtained by recycling of left over magnesia-carbon bricks, there are many intangible factors that have compelled us to take up this developmental work. Recycling of bricks has partially reduced our dependency on imported magnesia. This has also improved the environmental sustainability which is the burning topic today. This research work has enabled SRU Bhilai to successfully save 10% of its virgin raw material cost in FY2021-22.

10. REFERENCES

[1]. Madias, Jorge & Nicolas, San. (2017). A review on recycling of refractories for the iron and steel industry.

[2]. Kirsten moritz1 steffendudczig, hansgeorgendres, danielherzog, matthiasschwarz, Leandroschöttler, danielveres, christos g. Aneziris, Magnesia-carbon refractories from recycled materials, Volume4, Issue1,January 2022, Pages 53-58.

[4].Mukherjee, S., Pramanik, S. & Mukherjee, S. A Comprehensive Review of Recent Advances in Magnesia Carbon Refractories. Interceram. - Int. Ceram. Rev. 63, 90–98 (2014).

[5].Kyei-Sing Kwong and James P. Bennett, "Recycling practices of spent MgO-C refractories",Journal of Minerals & Materials Characterization & Engineering, Vol. 1, No.2, pp69-78, 2002.

[6]. Ewais, Emad. (2004). Carbon Based Refractories. Journal of The Ceramic Society of Japan - J CERAMIC SOC JPN. 112. 517-532. 10.2109/jcersj.112.517.

Insight into converter bottom purging

Kaushik Dasgupta
RHI MAGNESITA INDIA LIMITED
kaushik.dasgupta@rhimagnesita.com

Abstract

A bottom purging element in a BOF is not just another piece of magnesia carbon brick that one builds slots into and watch it delivering the gas! An inadequately developed element will fail under thermomechanical stress and result in excessive wear and/blockage of slots at a very early stage of converter campaign, so that metallurgical benefits associated with purging are achievable only for a meagre part of the campaign. The wear is typically concentrated around the gas blowing elements and the most frequented two reasons are attributed to erosion and thermo-mechanical spalling. Much has been discussed about the erosion aspect, like there is a correlation between maximum erosive wear and the gas flow rate and that maximum wear occurs at flow rates corresponding to the bubbling-jetting transition point of the gas stream in the bath. Not much has been discussed about the thermo-mechanical wear aspect. To this effect, this paper tries to explain the fundamentals of the critical material properties and design aspects that go into improving the bottom performance. As no discussion on bottom purging element is complete without a mention of the dynamics of the gas flow the system handles, basics of fluid dynamics that upholds an efficient BOF bottom purging have also been discussed in brief.

Keywords -compressive stress; fracture strength; fracture toughness; back pressure; mass flow; volumetric flow

INTRODUCTION

MHP (Multi Hole Plug) purging plug designs for inert gas bottom purging with flow rate optimized pipe diameters and number of pipes, have been established as widely accepted state-of-the-art for some decades. Such designs are based on 100% top-grade fused magnesia, top-grade graphite, optimized grain size distribution, and additives.

Efficient purging until the end of the BOF lining campaign is the target of all gas purging projects in BOF shops and is affected by the applied range of gas flow rates, the clogging potential, and the wear rate under particular process conditions.

The MHP design provides a much more appropriate gas bubble distribution above the purging plug with a higher share of small gas bubbles. The higher specific surface of the small gas bubbles increases the gas purging and metallurgical efficiency.

A. Temperature distribution in bottom during blowing

Without bottom-blowing, the measurements of bottom show regular fluctuations of the temperature during the cycle(empty-filling-blowing-tapping-empty). The temperature starts growing at the beginning of filling. After tapping the lining cools down. During bottom blowing, the inert gas cools down the lining around an active bottom blowing element (cold spot) and the cooling effect is proportional to the flow rate. Hot face

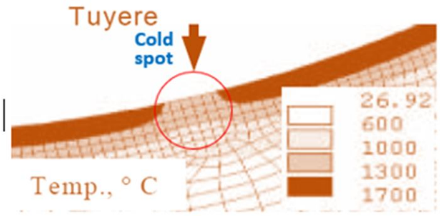


Fig.1 Hot face temperature around cold spot

temperature around purge element is in "stiff" range than rest of the bottom **(Fig1)** and hence compressive stress here is much higher than rest of the bottom **(Fig.2**).

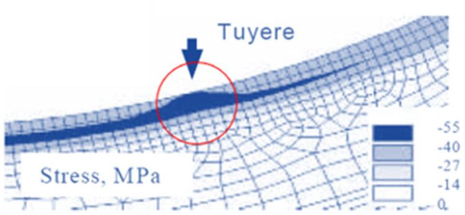


Fig.2 Compressive stress around cold spot

B. Plastic strains (compressive damage) during blowing

Compressive stress is often high enough to exceed material strength that makes the blowing element and bricks surrounding it, most vulnerable to compressive spalling **(Fig.3).**

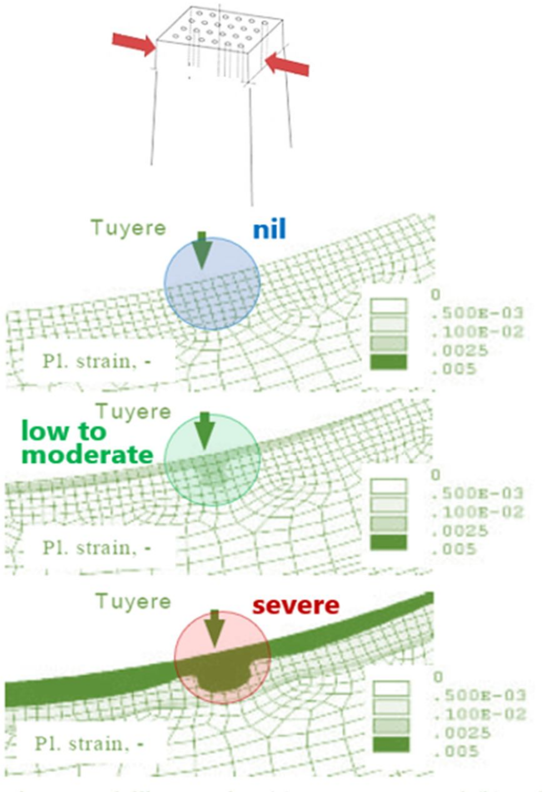


Fig.3 Varying degrees of compressive damage around cold spot during blowing

C. Strength and fracture toughness

MgO-C purge plug manufacturers are often tempted to use a refractory that is as strong as possible so that the material can withstand the stress due to cyclic loading. Well, this holds good so long as the system remains free of cracks! But cracks in MgO-C refractories exposed to fatigue conditions are inevitable!!

Once a fatigue crack initiates, it grows a small amount with each loading cycle (empty-filling-blowing-tapping-empty). The crack continues to grow until it reaches a critical size, which occurs when the stress intensity factor of the crack exceeds the fracture toughness of the material and typically completes fracture of the structure.

In these situations, knowledge of the fracture toughness is required to determine how long the brick can remain in service before the crack grows so long that the intact cross-section cannot support the load, and the brick fractures.

So, designers must be concerned with both the strength and the toughness of the material being produced.

The strength must be large enough so that the material can withstand the applied loads without deforming.

At the same time, the toughness must be sufficient for the material to withstand the propagation of fatigue cracks without failing catastrophically. The optimization of strength and toughness is the key here.

For a given load, as fracture toughness increases, the refractory can tolerate a longer crack before fracturing!

D. Two important parameters for selecting the right kind of formulation for bottom purging elements

Resistance to initiation of crack is important but more important is how ably we can control the crack propagation once it is generated!

This is where the right formulation of the matrix with respect to quality of magnesia aggregate and graphite flakes used, the grain size distribution, aggregate-matrix interface, porosity, right additives, and binder, come into play.

Only a full proof matrix can promote an effective tortuousness of crack path that transforms crack "activation energy" and energy dissipation, from "burst type" to "slow releasing type".

1) Resistance to crack initiation R

$R=\sigma (1-\upsilon)/ \alpha E$

R represents the maximum temperature gradient before cracks in the material are formed. That is, the higher the value of R, the greater the resistance to nucleate cracks due to stress by thermal origin

2) Resistance to crack propagation R'''

$R'''=E/\sigma^2(1-\upsilon)$

R''' indicates the minimum elastic energy, in the fracture zone, available for the crack propagation. That is, the higher the value of R''', the greater the resistance to propagation of cracks.

Here,

σ is the thermal stress

E is the Young´s modulus

α is the coefficient of linear thermal expansion

υ is the Poisson´s ratio

Of the two, the parameter R´´´ is more relevant in refractories since these materials often contain a large population of inherent flaws (pores and microcracks).

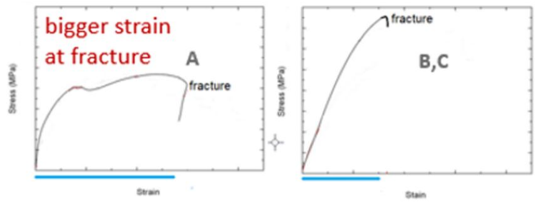
Example:

Brick	*σ_F (MPa)*	*ε_F (%)*	*R (^{O}C)*	*R''' ($x10^{-5}$ Pa^{-1})*
A	*23.40*	*0.50*	*171*	*2.90*
B	*37.40*	*0.31*	*327*	*0.80*
C	*24.10*	*0.34*	*330*	*1.10*

-The brick "A" meets the best combination of parameters R and R'''

- Despite having a lower value of fracture strength σ_F, "A" has a higher value of deformation % at fracture, ε_F owing to a much better placed R''', thus increasing the strain at fracture **(Fig.4a)**.

For "B" and "C", the higher values of fracture strength is offset by a speedier propagation of a fatigue crack to the point of fracture (lesser values of R''') **(Fig.4b).**



Stress vs. Strain

Fig.4a: brick A Fig4b: brick B, C

E. Factors needed to be addressed

1) Material properties

The most important parameter is the material flexibility and strength.

The right balance of the two!

2) Bottom structure

Use of different qualities around bottom blowing elements and rest of bottom.

3) Optimization of bottom blowing process

Reduce the cooling effect of the blown gas (optimizing flow rate, channel size).

F. Concepts of fluid dynamics that go into making an efficient bottom purging

Fluid dynamics is basically a set of empirical and semi-empirical laws derived from flow measurement, giving them a systematic structure and using them to solve practical problems.

Simply put in, it addresses how fluids behave and how they interact with their surrounding environment.

1) Back pressure

When a fluidic substance moves through a pipe, it builds up a lot of kinetic energy and inertia. When that energy hits a wall (say a blockade by infiltrate in the plug), it bounces back like ripples. This has two major effects:

a) Increases pressure in the pipe when the fluidic substance first encounters a change. This effect is commonly called a fluid hammer. The fluid bounces back at the fluid attempting to come through the pipe. This will increase the fluid present in that small section of pipe and, thereby, increase its pressure.

b) It also slows down the movement of all the fluid in the pipe, from the place of change all the way back to the source.

So, the flow is essentially in the same direction, but the flow is reduced due to resistance.

2) Open-Loop vs. Closed-Loop Fluid Control

When we use a fluid to power a process it is essential that we should have the ability to control the fluid too. It all boils down to either open-loop control or closed-loop control.

In the simplest terms, if the output response (result) generated is directly related to the input (action) supplied by the controller via feedback from the process itself, the system is closed-loop, if not it is considered open-loop.

For obvious reasons, open-loop systems are less accurate, less repeatable and (generally) less costly. An efficient CIP always thrives on a closed loop control.

3) Volumetric flow rate

It is a measure of the 3-dimensional space that the gas occupies as it flows through the instrument under the measured pressure and temperature conditions. Volumetric flow rate can also be called actual flow rate.

Volumetric Flow Rate is dependent on Pressure & Temperature and hence are recommended for measuring volumetric flow when high accuracy is not needed.

4) Mass flow rate

It is a measure of the number of molecules that flow through the instrument, regardless of how much space those molecules occupy. It is often expressed as a standardized (or normalized) volumetric flow rate, which is the amount of space that those molecules would occupy if measured under standard temperature and pressure conditions (STP, or NTP).

Mass Flow Rate is independent of Pressure & Temperature and hence more reliable with higher accuracy and repeatability.

Relation between volumetric flow rate and mass flow rate:

$\tilde{V}=nRT/(mP)*\dot{m}$ Where

$\tilde{V}$=Volumetric flowrate

$\dot{m}$=Mass flow rate

m=molar weight

n=moles

R=real gas constant

P=Pressure

T=Temperature

Example: a 200sccm flow sensor with a mass flow rate of 0.250 g/min (200sccm) of nitrogen.

	$\dot{m}$	**0.250**	g/min
	m	28	g
	n	1	mole
	R	82.1	(cm^3*atm)/(mole*K)
STP	**P**	1	atm
	T	273.15	^{O}K
	$\tilde{V}$=	**200**	cm^3/min

This calculation refers to standard pressure & temperature. Here volumetric flow rate $\tilde{V}=200cm^3/min$ can also be referred to as mass flow rate $\dot{m}$=200sccm/min (equivalent to 0.250g/min). For non-standard conditions (P and T changing), volumetric flow rate $\tilde{V}$ will vary but mass flow rate remains same i.e. 200sccm/min (equivalent to 0.250g/min) as long as we do not bring about any change in mass.

5) Pressure control valve (PCV)

The PCV is what we use to regulate the pressure of a fluid passing through the pipe.

PCV is controlled using a pressure transmitter (PT) which is basically an electronic pressure gauge that sends signals to the PCV and tells it whether there is enough pressure entering the equipment. The PCV opens or closes to compensate. This is based on the set point predetermined by an engineer.

They are not designed to act as flow controllers.

6) Flow control valve (FCV)

FCV is the same except it gets its signals from a flow transmitter (FT). FT is basically a flow meter that can communicate with a related valve. The FCV opens or closes based on the required flow rate and the signals it receives from the FT.

Pressure and flow control valves can look almost indistinguishable sometimes, except for the sensing mechanism, which is monitoring the variable we need to control.

G. Mass flow controller.

The mass flow controller (MFC) will automatically control the flow rate of a gas according to a set flow rate sent as an electric signal, the measured flow being mass compensated for any change in temperature and pressure.

Individual MFC per individual plug is thus the essence of efficient purging control.

Practical problems encountered with a system that works without mass flow controller:

Long response time:

Systems need a few minutes until the new set values of flow rates are reached (MFCs have a response time <500ms.)

This long switchover time increases the risk of blockage.

Inability to ensure precise and stable flow regulation:

Particularly at low flow rates, this is especially critical during slag splashing and de-slagging, because minimum gas flow rates are normally applied during these process steps.

Merits of MFC

-Wide regulation ratio 1:50 of MFC (i.e., from 24Nl/min to 1200Nl/min or from 32Nl/min to 1600Nl/min).

-Fast step response of the MFC (5-95% in less than 1 second.

-High accuracy of MFC @+/-1.5%.

H. Pressure, Flow, Velocity:

Determining which variable is important!

Understanding the interdependent nature of pressure, flow and velocity is important when designing a system but more important is understanding when each variable is the critical design parameter.

Velocity

The force of a fluid comes from the fluid impacting at high velocity. The velocity is increased by forcing a volume of fluid through a constricted outlet. While the fluid is moving very quickly, it is not necessarily a high volumetric flow rate; this is a common misconception.

Flow

Flow is critical when the fluid needs to fill a space. We need to supply a given volumetric flow rate that continuously fills and replenishes the application space.

Pressure

If an application is expected to have a high back pressure, the system must be rated to operate at that pressure. Characteristics of a system with a high level of back pressure include multiple lengths or long lengths of hose or pipe and applications where gas is forced through small openings.

CONCLUSION

Bottom purging refractory is not all about strength but also about resilience with a unique blend of fracture toughness and higher value of deformation % at fracture, that makes it a premium among all MgO-C qualities. Only an adequately developed element will perform under the shear thermomechanical stress it is put into and reap the metallurgical benefits for an entire BOF campaign. It is also worth mentioning here that a bottom purging element alone doesn’t suffice the purpose of an efficient purging system. It is only a part of a much bigger setup that gives due cognizance to the interdependent nature of pressure, flow and velocity of the gas the system handles.

References

[1] Marcus Kirschen, Karl-Michael Zettl, Roland Ude –RHIMAGNESITA, Austria,” BOF process improvements by enlarged gas purging portfolio from moderate to very high gas flow rates”.

[2] N. Schmitt, Y. Berthoud, J. Poirier, “Tensile behavior of magnesia carbon refractories”.

[3] Edgardo Roque Benavidez Elena Brandaleze Yamila Soledad Lagorio Sebastián Emiliano Gass Analía Gladys Tomba Martinez, “Thermal and mechanical properties of commercial MgO-C bricks “

[4] K. Andreev, W. M. Heijboer, R. Siebring (Corus RD&T, Ijmuiden, The Netherlands),” BOF bottom wear around tuyeres and blowing elements-thermomechanical investigation to optimize the lining performance “.

[5] Andreas Viertauer, Michael Schacher, Stanislav Ulitsky, Matthias Scheibmayr, Erich Röllin, Reinhard Ehrengruber, Matthias Stalzer, Oswin Dolzer, Teodor Staicu, Thomas Kollmann, Bernd Trummer, Alexander F. Orlov, Alexander Papushev, Sergey Razgulyaev, Marcus Kirschen and Sergey G. Zhuravlev,” Implementation of BOF Gas Purging Technology and Current Process Results After One Year of Successful Operation at Severstal Cherepovets”.

[5] Hai Tang, Guangwei Guo, Qingyou Zhu, Wenjie Yuan, The State Key Laboratory of Refractories and Metallurgy, Wuhan University of Science and Technology, Wuhan 430081, P.R. China,” Prediction of Fracture Toughness of Magnesia-Carbon Bricks Based on Fractography”.

[6] J. Twyman, *Twyman Ingenieros Consultores. Rancagua. Chile,” Water hammer in a pipe network due to a fast valve closure”.

[7] Benchawan Wiwatanapataphee, Yonghong Wu, I. Ming Tang, and Shaoyong Lai,” Fluid Dynamics and Computational Engineering”.

A case study - use of recycled material in RH degasser lower vessel magnesia chrome brick

Avishek Mitra[a], Sanat Kumar Hazra
Dalmia Bharat Refractories Limited, Rajgangpur, India
mitra.avishek@dalmiaocl.com

Abstract

As the demand of clean steel has increased particularly with very low carbon and hydrogen content, RH degassing process is gaining popularity among steel manufacturers. RH degasser is one of the best among various secondary refining process due to its high refining efficiency and productivity. Usually, various types of $MgO-Cr_2O_3$ bricks are used in different areas of the vessel because of their excellent resistance to erosion and corrosion, high temperature stability, low thermal expansion and high hot strength.

The objective of this work is to develop RH lower vessel brick by using recycled material with similar life that we were getting by using 100% virgin material. The thermo-mechanical with different amount of recycled material have been studied. The results shows that 30% addition of recycled material with a special additive have a great effect on the critical properties and has given similar life as virgin material.

Keywords - RH Degasser, Magnesia Chrome, recycled material;

INTRODUCTION

The Ruhrstahl Heraeus (RH) Degasser is the globally preferred equipment to manufacture high quality vacuum treated steel purified to ppm level of C, H, and N. Examples of such steel are ultra low carbon steel (<30ppm C) for auto-mobile application, crack resistant rail grade steel (<1.5ppm H2, <40ppm N_2) and electrical steel for transformer core. The RH degassing vessel involves complex reactions between molten steel, gas, slag and inclusions from refractory. The refractory lining in the RH vessel and in the snorkels are subject to severe operating conditions like high speed of liquid steel circulation between the RH vessel and the ladle, the chemical reactions in the RH vessel, the violent temperature change, the O_2 blowing and vacuum conditions inside it. The proper choice of suitable refractory materials for the RH lining is of high importance to improve the RH lining life. Usually various parts of the RH Degasser are lined with different grades of magnesia chrome ($MgO-Cr_2O_3$) bricks. $MgO-Cr_2O_3$ refractories are known for their excellent resistance to erosion and corrosion, high temperature dimensional stability, low thermal expansion and high hot strength.

One of the main constituent of these RH lower vessel refractory is fused magnesia chrome co-clinker. The base raw material for manufacturing this co-clinker is magnesia. Natural magnesite ($MgCO_3$) deposits are the main source of magnesia; other sources are seawater and brines.

A case study - use of recycled material in RH degasser lower vessel magnesia chrome brick

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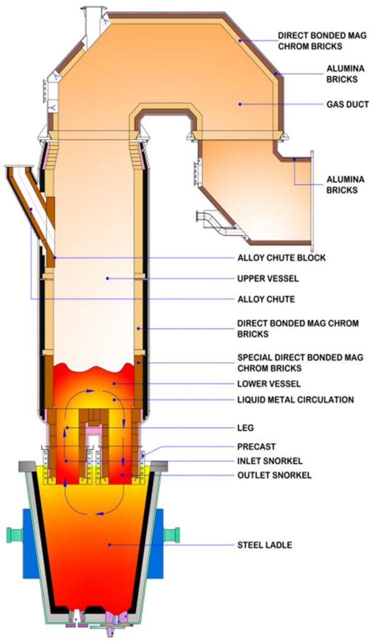


Fig 1 - A schematic representation of Ruhrstahl Heraeus (RH) Degasser

This magnesia is one of the most important raw material for refractories with highest annual consumption. On the other hand, large quantities of used refractories, including Magnesia Chrome, are generated annually, especially in the ferrous and non-ferrous industry.

The recycling of the used refractories is currently gaining in importance for both economic and ecological reasons, such as increased prices for raw material, dependence on raw material supplies, and the need to reduce CO_2 emissions and energy consumption. Recycled Magnesia Chrome refractories are used in land-filling at various sites. However, the highest benefit can be achieved when they are used as secondary raw materials for the production of refractories.

In this paper, we have investigated the use of Magnesia chrome recyclates for the production of Magnesia Chrome refractories for RH lower vessel. The final results have been discussed in this work.

EXPERIMENTAL

The following raw materials were used for the production of the magnesia chrome specimens:

- fused magnesia chrome co clinker (FMCR) in the grain size fractions 0–1, 1–3, and 3–5 mm,
- fine-grained magnesia chrome co clinker ($d_{50,3}$ = 71 µm),Low silica chromite in the grain fractions 0-1 mm,
- Magnesia Chrome recyclate MCR65 in the fractions 0–1 and 1–3).

A combination of Mollases and dextrine along served as a binder mixture. A special ultra fine additive was added to improve the hot properties by formation of in-situ spinel.

The morphology of the magnesia chrome recyclate MCR65 can be seen in Figure 2, showing a scanning electron (SEM) micrograph of the 0-1 mm aggregate size fraction of this raw material. In the case of the recyclate, the term “aggregate” is used because it largely consists of composite grains of magnesia chrome and chromite particles. The chemical analysis of the aggregate is as per Table 1. Table 1: Chemistry of MCR65

MgO (%)	SiO_2 (%)	CaO (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Cr_2O_3 (%)
65.80	1.20	1.15	6.20	7.00	18.10

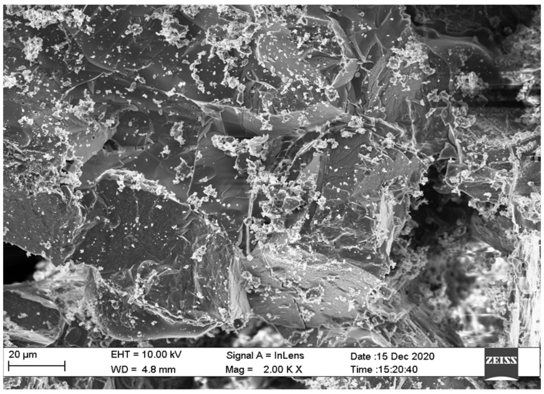


Fig 2: FESEM micrograph of MCR65

Different batches of magnesia chrome bricks were manufactured, all in the same base material but different percentages of MCR65.

Table 2: Trial Formulations

Raw Materials	RS	T-1	T-2	T-3	T-4	T-5
FMCR	85	75	65	55	45	35
Chromite	15	15	15	15	15	15
MCR65		10	20	30	40	50

The set of trial samples were shaped into bricks by using industrial hydraulic press with a specific pressure of 1.8 Ton/cm^2 and samples were dried at 110°C for 24 hrs and then at 160°C for another 24 hrs. After drying, the samples were fired at 1800°C with predetermined heating schedule and soaking time in high temperature tunnel kiln. The fired samples undergo testing as per the industrial testing practices. Apparent porosity (AP), bulk density (BD), cold crushing strength (CCS), and hot modulus of rupture (HMOR) was determined by the conventional three-point bending test conforming to ASTM C133-97 at 1400°C, using HMOR testing apparatus (Netzsch 422, Germany). Micro structure analysis were done by using Optical Microscopy (Leitz orthoplan pol optical microscopy with image analyzer). Each value of the tested samples was average of three parallel samples. Pore size analysis was also done along with rotary drum test with slag and metal at 1650°C to 1700°C for 10 hours.

RESULTS AND DISCUSSION

Table 2 shows the physical properties of different batches of Magnesia Chrome bricks. The porosity increases with increase in recyclate percentage, but the increase in rapid after if recyclate percentage increases above 30. In T-1, T-2 and T-3 the apparent porosity is higher than RS with 100% virgin composition, the change in porosity is minimal. The same is seen with bulk density data also. As bulk density is closely related with apparent porosity, the BD values decreases with increase of recyclate percentage in the bricks. In case of HMOR at 1400°C, the values are nearer to that of RS till 30% of recyclate build up. But after that, the values fall rapidly and at 50% recyclate material addition, the HMOR value is almost 35% lesser than that of RS.

Optimum quantities of different size fractions are selected based on the Andreasen's equation to achieve highest packing density and subsequently low porosity. As, impurity is very low and matrix is dense due to proper selection of coarse to fine ratio, the bricks shows high HMOR. Addition of ultra fine additive increases the bulk density because the additive is denser than FMCR and chromite.

Table 2: Physical properties of different Trial batches

Properties	RS	T-1	T-2	T-3	T-4	T-5
AP (%)	16.5	16.8	16.9	17.1	18.8	20.4
BD (gm/cc)	3.26	3.25	3.25	3.24	3.21	3.18
CCS (kg/cm^2)	649	668	579	592	523	501
HMOR (kg/cm^2)	87	85	82	81	72	56

Erosion by turbulent circulation of molten steel and slag is severe in the lower vessel due to argon gas bubbles. Higher HMOR implies higher resistance of the refractory to this type of erosion. The HMOR of T-1, T-2 and T-3 are closer to that of RS which was giving good life in RH lower vessel. The high strength indicates good bonding due to high firing temperature and a low-impurity matrix..

Fig 2 shows that the pore size distribution analysis of samples RS, T-1, T-2, T-3, T-4 and T-5. Addition of special ultra fine additive in the trials closes the interstitial pores which is very clear from the PSD. The percentage of finer pores are greater in number in RS and slowly reduces with the increase of recyclate material percentage in the trials.

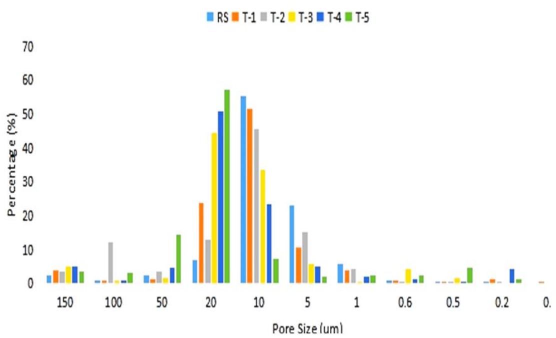
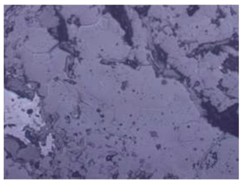


Fig 3: Pore size Analysis of the Trial samples

Pore size distribution is an important factor when evaluating the corrosion resistance. The fewer pores and the smaller in size create dense matrix structure and able to keep the grains embedded.

Fig 4 shows the micro-structural analysis of T-1, T-2, T-3, T-4 and T-5. The matrix part of T-5 nd T-4 have loose texture due to presence of high porosity surrounded by magnesia chrome grains. Fig 4C shows the micro-structural analysis of T-3. The matrix is denser with less number of channel and open pores due to better sintering between grains. The microstructure of T-1 and T-2 along with T-3 are almost similar to that of RS.



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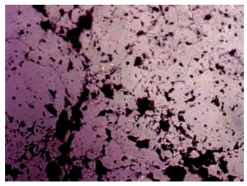

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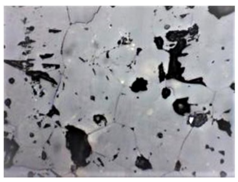

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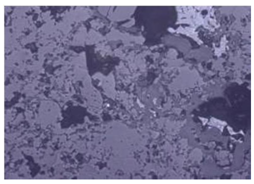

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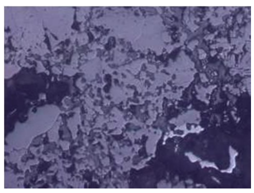

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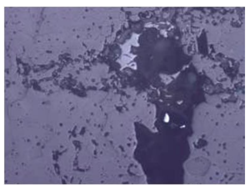

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Fig 4: Photo micro-graphs of different batch compositions

Fig 5 shows the slag corrosion results of all the trails. It is clear that the corrosion index of T-1, T-2 and T-3 are almost closer to that of RS while in T-4 and T-5 the index falls sharply.

High surface area due to direct bonding and less amount of pores, provides better distribution and in-situ spinel formation along with large crystal size of magnesia grains - improves corrosion resistance. Formation of large number of sub-micron pores (<0.2µm) by high temperature firing and addition of special ultra fine additive reduces the penetration of metal/slag due to large contact angle between refractory and metal/slag

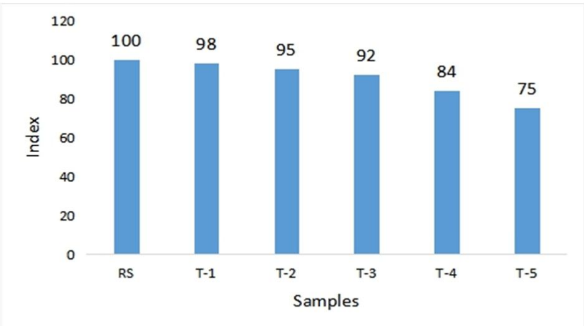

Fig 5: Corrosion Test Data of samples

FIELD TRIAL

In Plant A where the RS bricks were being used in RH lower vessel was giving life around 80-85 hts and after the total life, the left over thickness (LOT) was around 120-130 mm.

5 sets of Rh bricks with formulation T-3 was sent to Plant A and average life achieved 83 hts DIDO with a highest life of 87 hts. The used bricks were collected and the LOT was found around 100 mm and the penetration was also very less. In the below comparison (Table 3), it is clear that, the bricks with recipe T-3 have much good corrosion resistance an can be used in lower vessel with similar performance compared to RS.

Fig 5: LOT comparison

CONCLUSION

The stepwise replacement of virgin raw materials with Magnesia chrome recyclate for the production of Magnesia chrome bricks for RH lower vessel was investigated. Magnesia Chrome co-clinker was substituted for the recyclate in various ratios. The recyclate content in the mixture was up to 50 wt%.

It is observed that with increase in recyclate percentage, the porosity of the samples increases. But this increase is very high after the recyclate content goes over 30%. The HMOR of the samples also decreases with increase of recyclate percentage. The optimum quantity of recyclate material with properties almost similar to the 100% virgin sample was found to be 30%. This trial sample with 30% recyclate material was used in Plant A and the result found was almost similar with that of 100% virgin sample.

ACKNOWLEDGEMENT

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REFERENCES

[1] Alper A. M. High Temperature Oxides. Academic Press, Inc., 1970.

[2] Haldar MK, Tripathi HS, Das SK, Ghosh A. Effect of compositional variation on the synthesis of magnesite-chrome composite refractory, Ceramic International, 2004, 30, 911–915.

[3] Dinger DR, Funk JE. Particle packing II – Review of packing in polydisperse particle systems. Interceram 1992;41(4): pp. 95.

[4] Andreasen AHM. Ueber die Beziehung zwischen Kornabstufung und Zwischenraum in Produkten aus losen Körnern (mit einigen Experimenten). Kolloid-Zeitschrift 1930;50(3): pp. 217-228.

[5] Myhre B. The effect of particle-size distribution on flow of refractory castables. In: Proceedings of the 30th Annual Symposium on Refractories; 1994 March 25; St. Louis, Missouri: pp. 19-22

[6] J. Poirier : La thermodynamique : un outil indispensable pour interpréter la corrosion des céramiques à haute température, CD-Rom, Matériaux 2006, Dijon, France, (2006). 8. FactSage : www.crct.polymtl.ca/fact

[7] F. Qafssaoui, J. Poirier, J.P. Ildefonse, P. Hubert :Influence of liquid phase on corrosion behaviour of andalusite-based refractories. Refractories Applications Transactions, 1 (2005) , 2-8

[8] B.N. Samaddar, W.D. Kingery, A.R. Cooper :Dissolution of alumina, mullite, anorthite, and silica in a calcium-aluminum-silicate slag. Journal of the American Ceramic Society, 47 (1964), 249-254

[9] S. Zhang, W.E. Lee : Use of phase diagrams in studies of refractories corrosion, International Materials Reviews. 45, 2000, 41-58

[10] Oliveira IR, Studart AR, Pileggi RG, Pandolfelli VC, Dispersão e empacotamento de partículas. São Paulo: Faz. Arte Editorial, 2000 [in Portuguese]

[11] Magnesia-carbon refractories from recycled materials - Moritz K, Dudczig S, Endres HG, Herzog D, Schwarz M, Schöttler L, et al., Int J Ceramic Eng Sci. 2022;4:53–58.

Optimization of EAF Tap weight by Improving the Refractory Design In SMS-1 & Best Operating Practices JSW Odisha

Asis Kumar Sarkar & Amit Tiwari
[1]*JSW Steel Sambalpur, Odisha asis.sarkar@jsw.in Cell 8092086247*

Abstract

As the Indian Steel Industry has grown up and matured EAF route steel production getting popularize day by day & EAF steel production participated in an ever more competitive market , off late after stabilizing the JSW Vijaynagar plant in BF- BOF route , JSW Steel has entered in the EAF route steel making by the acquisition of Ispat – Dolvi 2007 ,M/s Bhusan Steel Jharsugda 2021 & Monnet Ispat 2017 & Creating new facility in Vijaynagar [SMS-III] 2016 , this competition has led to a continuous search for lower cost alternative for energy input materials ,Optimize / Increase the tap weight and reducing the processing time by increasing the hot metal pouring rate by redesign the Launder & time and Oxygen flow and operation excellence .

Over the year electric steel furnace community of the operation has develop a variety of Technological Improvement geared to increasing the EAF productivity , operators has emphasized the lowering of the operation cost per mt of steel produced by increasing the Tap Weight , reducing the Tap to tap time improving the quality of Inputs like hot metal , lime , pet coke , Dolomite and DRI etc .

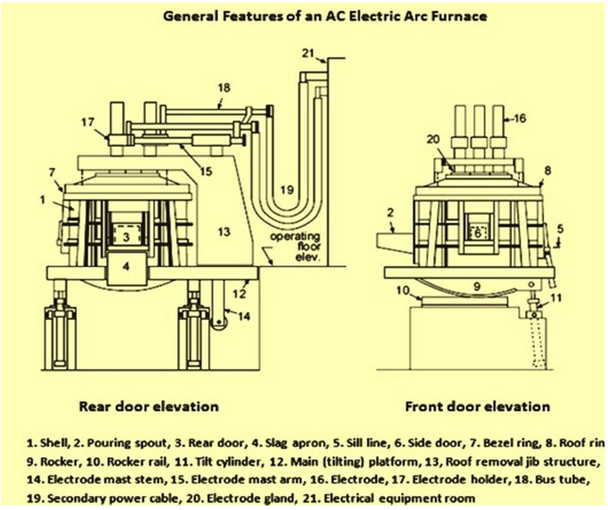
Depending on the market condition , JSW Steel may run with different goal and goal of Maximizing the cost effective use of resources , When the market demand is high the goal may be to maximize EAF through put and number of Heat taped in a day , the objective of work is to optimize the Tap to Tap time by adopting the best operating Practices .In considering the very high demand of HR Coil , JSW Steel have decided to Increase the through put of four EAF of SMS-1 of JSW – Odisha of originally designed capacity 95 mt Tap weight with 70 minutes processing time to 105 mt Tap weight & 60 minutes processing time by reengineering the Bottom shell and upgrading the quality of Refractory & Lining pattern and Increasing the Hot metal pouring rate [3 mt/min to 6 mt/ min] and operation excellence .The Job was undertaken immediately after taken over Bhushan by JSW Management and Idea conceptualization to projects completion time is less that 6 month , all the 4 EAF [Eight Number of Bottom Shell] redesigned , In house modification of Bottom Six number Bottom shell , discarding two old shell by new shell , Up gradation of quality of Bottom shell lining and modification of Steel Ladle and Hot metal ladle & modification of loco Car of EAF Processing the Project was take up simultaneously and completed in six month from OCT-21 March 22 .The work was successful and completed in 31st March 22 resulting 10-20 %increase of the capacity of SMS-1 & Quality of steel also improved as hot heel was improved.

Keywords - Productivity, Foaming Slag , Tap to Tap Time , Hot Heel

INTRODUCTION

The Global steel Industry is seeking Innovative new solutions to the challenges of CO2 emissions and opportunity for the Investment in sustainable business and Operating Models. In this environment the electric arc furnaces [EAF] present an opportunity for those regions where there is sufficient supply of secondary and other form of raw materials. Switching an Increasing Proportions of global steel production to the EAF could give a significant benefit, but it is hindering by the challenge of energy availability and product quality.

Design Feature of an Electric Arc Furnace .
Electric Arc Furnace [EAF] used for steel making apply high current and low voltage electric energy to change the raw materials and then by melts and refining them . EAF is a bath Furnace which consist of Refractory Lined vessel covered with a Refractory & Water cooled panel Roof through which Graphite Electrodes entered in the furnace. General features of a typical AC Electric Arc Furnace are given below.



EAF has a large bowl shaped body with a dish shaped hearth. The shell has a refractory lining inside called bottom shell and no water cooling system in the bottom shell. Above the bottom shell, top shell is then placed which is cooled by 12 nos of water cooled panel and 3 nos of KT/Cojet lances for injection of oxygen in the bath. The bottom shell is the main reaction chamber which is covered by top shell and removable roof which is made of water cooled panel and refractory precast which is surrounded by water cooled ring. It is feed with 3 phase alternating current (AC) and has 3 graphite electrode (UHF) which is connected by flexible cable and water cooled cooper tubes.

The design of Electric Arc Furnace has change considerable in recent years. Emphasis has been placed on making furnace large volume by re-designing the bottom shell profile. Increasing power input rates to the furnace and increasing the speed of the furnace movement in order to minimize power off time in furnaces in order to reduce unproductive time and minimize tap to tap time. The different components of EAF fall into different functional group as follows.

1. Main furnace structure (Bottom shell, Top shell & Roof) it contains the Hot metal, DRI, Scrap, fluxes & liquid Steel. It also contains 3 nos of purging system (DPP) and taping system(EBT) & Slag door. In top shell 12 nos of water cooled panel, launder entry point & 3 nos of KT/Cojet lances.
2. Components which allow the movement of the furnaces of its main structural pieces it include rocker arm, hydraulic system & Mechanical supporting system.
3. Components that support the supply of electric power to the EAF like flexible water cooled cable and must beam.
4. Auxiliary process equipment which may be outside the furnace or around the periphery like coal/coke injection system, refractory gunning, robotic fettling machine, moveable launder for hot metal pouring

A. Modification of EAF Structure:

In this modification extensive refractory design and improvement in quality of bottom shell has been done keeping all other area of top shell intact and effectively 1.5 m3 volume in the bottom shell was increased for getting higher capacity of the bottom shell. In order to reduce the tap to tap time pouring rate of hot metal has been increased from 3 MT/Min to 5 MT/Min by modification of launder. The launder refractory design has been changed by increasing the capacity of reservoir tank and introducing PCPF shaped at the entrance in the furnace to counter the cantilever action due higher castable weight at the reservoir tank. The total launder weight increased and the support system also required strengthened. Modification of the bottom shell was done with introduction of improved quality direct bonded magnesite safety bricks at bottom 3x75 mm and side wall. Above the Safety Bottom bricks of 450 mm MgO-C bricks with relatively lower carbon [Max8%] used at the bottom content the heat properly. Above MgO-C bricks 300-400 mm Dry Ramming Mass was put with the help of pneumatic poker machine to maintain proper profile to maintain the hot heal qty. Quality of ramming is regulated at 1.5 -2 mt /hour to check the quality & strength developed of ramming checked by piercing a welding rod to a max length of 20 mm . 2 nos of Pneumatic poker machine is used to ensure proper de-airing and compaction at bottom and bank area . All the Steel Ladles capacity creased by modification in height and modification done in the transfer car to for increasing the clearance during entering the LF for secondary metallurgy in LF . The CSP caster speed also increased by increasing the metallurgical length from 6.34 m to 7.12 m by increasing the length of the 3rd Segment from average speed of 5mt/min to max speed to 6.5 mt/min .

Conclusions

All the design and modification done thru in house Technology Group and it took 6 months to modify all the Furnaces Bottom shell which was originally as per design 95 mt Tap weight capacity, Out of 8 shell two shell which was were discarded in the NDT test hence it was replaced by new shell and all the six shell are modified by keeping the bottom plate intact and peripheral shell [Circular Ring] was replaced and Bricks of the Bottom and side wall change as per design enclosed. All the Shell and Ladle capacity and CSP Speed increase Project work was completed in the March 2022 .

REFERENCES

[1] Electric Arc Furnaces Innovation ‘Addressing the Technology Challenges Paper no 3 Journal 2022.

[2] A Process model for EAF Steel Making , Clausthan University of Technology , Institute of Metallurgy AISTech 2006 may 1-4 Ohio USA vol -2.

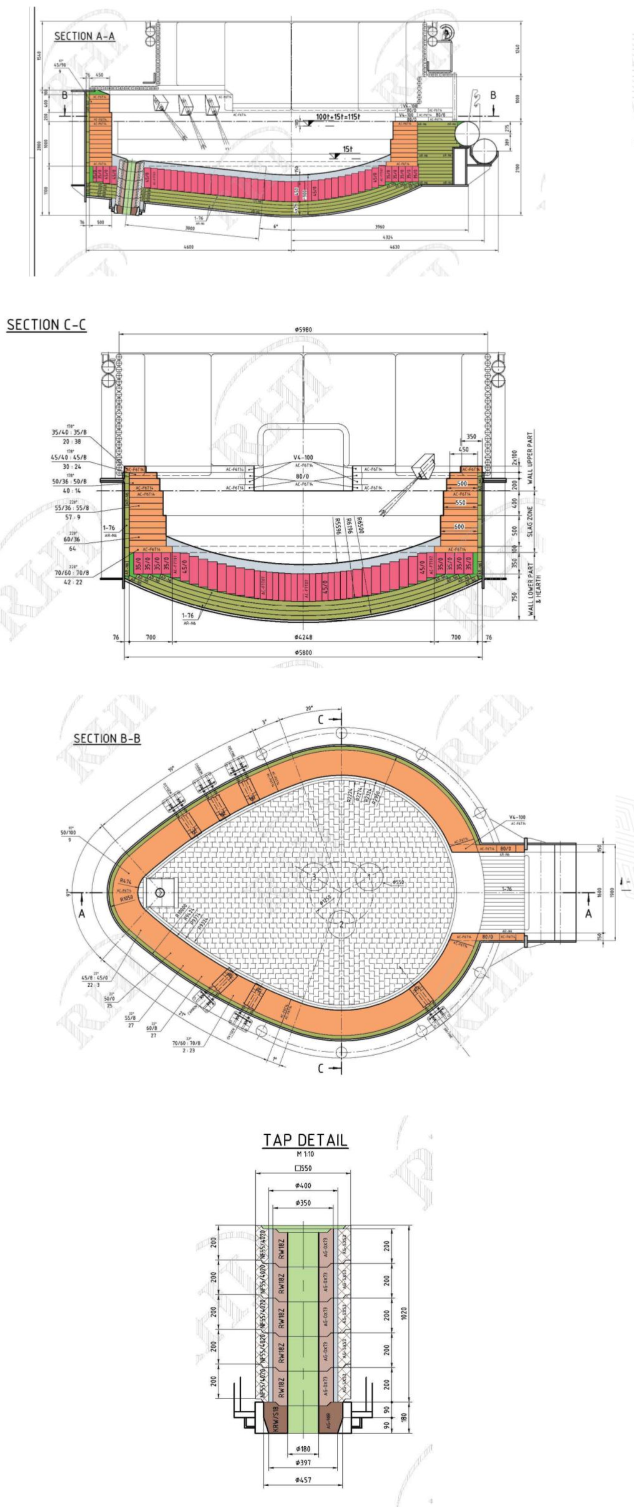
[3] Chemical &Process Engineering Research ISSN 2224-7467 Vol 28 2014.

[4] A Mathematical Simulator for the EAF Steel Making Process using Direct Reduce Iron , R.D.Morales , ISIJ International Vol 41 2001 , no 5 pp 426- 435 .

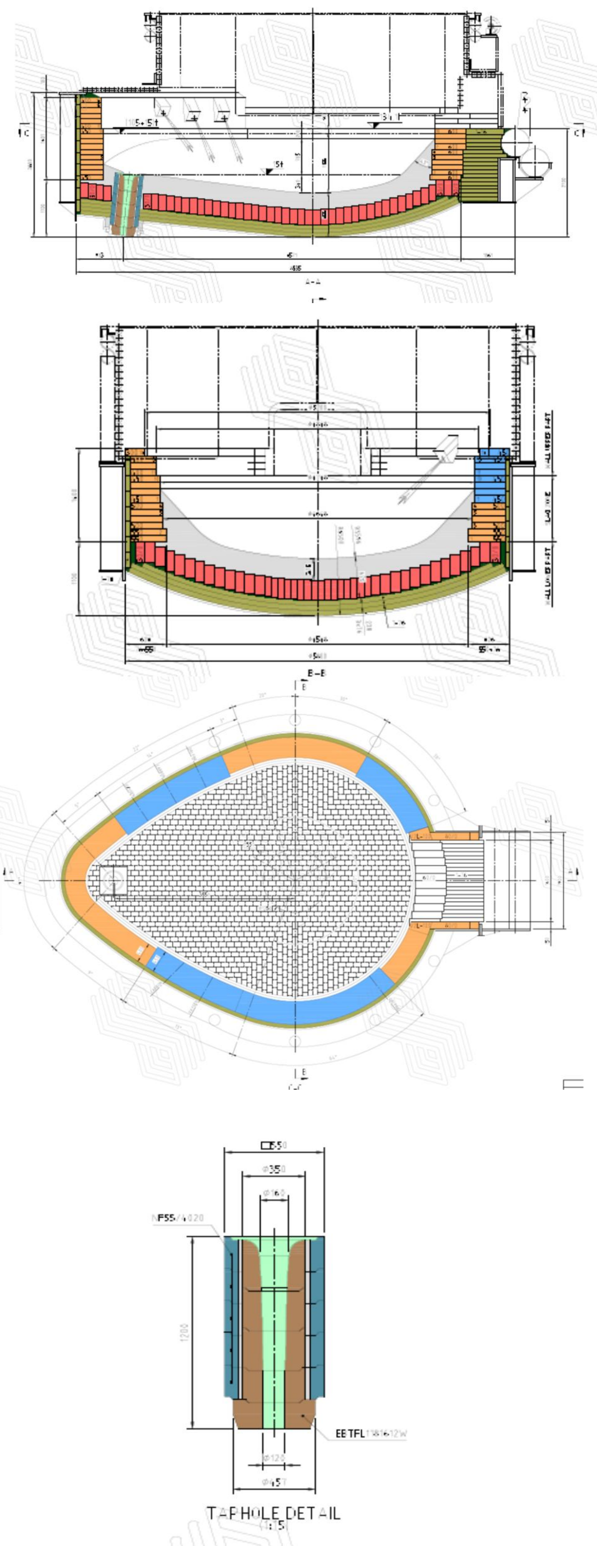
[5] Process Modeling of Steel Refining in Electric Arc Furnace [EAF] for Optimum Performance and Waste Reduction . Chemical and Process Engg Research , ISSN 2224 -7467 Paper – vol -28, 2014 .

[6] Study on Wear Mechanism of Refractories of EAF working lining and Roof & Refractory for EAF , SKMitra , BNGhosh , al. steel furnace Monthly Vol ix no 2 pp 103 – 113

Old Design EAF Bottom Shell



New Design EAF Bottom Shell



A Discussion on Importance of Spinel Bricks in Steel Making Processes

Deepak Mane
Maithan Ceramics Ltd.
deepak.mane@maithangroup.com

Abstract

Refractories an integral part of steel making, as Iron & steel Industry is the largest refractory consumer. Since long time refractory industry has undergone many vital changes in terms of technological developments like various manufacturing processes and raw material combinations. On the other hand refractory industry has always evolved with superior products to cope with the requirements of advanced steel making practices. This study evaluated journey on development and application of Spinel Bricks used in Steel Ladles for secondary refining of liquid steel in steel melt shops.

Technological advancements in steel making, like Ultra-Low Carbon Steels (like IF grade steel) manufacturing, creates an extraordinary demand for requirement of less/no Carbon refractories for secondary refining vessels like Steel Ladles. Also, it is today’s demand on possibilities for alternate solutions to an environmentally harmful chrome containing refractories. It is anticipated that an importance of Spinel bricks will continue to grow in coming years to meet challenging requirements of steel making processes.

Introduction:

Refractories undergo very high thermal/mechanical erosion and chemical corrosion due to molten slag reactions with refractory linings. Hence refractories are one of the major consumable in steel industry. The global refractories market size is projected to reach USD 42.30 billion by 2027, exhibiting a CAGR of 3.6% during the forecast period [2020-2027] in the Market Research Report published in July 2020 by Fortune Business Insights.

Automobile industry is the prime consumer of clean steel. In today’s scenario Fuel is the major source of energy in automobiles. In the coming years, energy conservation is major target towards an industry. In order to improve fuel economy and energy conservation, demand for high quality steels with improved strength to weight ratio, has been evolving and increasing day by day.

Advancements of steel requirements for deep drawing and thin sheet steel rolling with high strength for automobile sector. Stringent quality requirements with less impurities in steel such as – C, P, S, N, H & O etc. in order to achieve best deep drawing properties and high strength thin sheet steel rolling.

Hence, such technological advancements in automobile industry demands more clean steel. The need of clean steel is known to all of us, for any grade of steel with minimum or very low impurities, trace elements like Phosphorous & Sulphur and entrapped gas elements like Nitrogen, Oxygen, and Hydrogen etc. However, 20 to 30 ppm of carbon content in case of IF(Interstitial free) grade steels or max 50ppm of Sulphur and low carbon ppm in Electric grade steels, demands more stringent secondary refining requirements like RH degassing or vacuum degassing etc.

We have initiated efforts considering the need for customization of spinel refractory products for the stringent requirements for IF grade steel manufacturing.

Alumina-Magnesia spinel bricks with special characteristics such as volume stability during application, better spalling resistance, less slag penetration, and improved slag corrosion resistance. Spinel bricks were installed & put into an operation in 130, 180 and 350 MT capacity steel ladles in largest integrated steel plants in India.

Spinel (Alumina-Magnesia) Bricks for Steel Ladle Linings:

We evaluated our journey on development and application of Spinel bricks in Steel Ladles used for secondary refining of liquid steel in steel melt shops. Technological advancements in steel making, like Ultra-Low Carbon Steels (like IF grade steel) manufacturing, creates an extraordinary demand for requirement of Low/No Carbon refractories for secondary refining vessels like Steel Ladles. Also, it is today's demand on possibilities for alternate solutions to an environmentally harmful chrome containing refractories. It is anticipated that an importance of Spinel bricks will continue to grow in coming years to meet challenging requirements of steel making processes.

The need of clean steel is known to all of us, for any grade of steel with minimum or very low impurities, common trace elements like Phosphorous and Sulphur and gas elements like Nitrogen, Oxygen, and Hydrogen etc. However, 20 to 30 ppm of carbon content in case of IF grade (Interstitial free) steels or max 50ppm of each Sulphur and carbon in Electric grade steels, demands more stringent secondary refining requirements like RH degassing or Vacuum degassing etc.

Alumina-Magnesia spinel bricks is the widely accepted and most prominent option to meet stringent secondary refining parameters.

Advantages of Spinel Ladle bricks over conventional carbon containing refractories:

- Ease of secondary refining of Ultra-low carbon Steel (IF grade steel) and No Carbon pick up in steel from refractory lining.
- To enhance MZ (Metal Zone) & Bottom lining life of ladles to increase ladle life and in turn ladle turn-around.
- Reduced specific consumption of ladle refractories and hence cost reduction. Also indirect savings like reduction in preheating & manpower expenses.
- Energy saving because of less heat loss due to heat radiation through ladle lining & shell. This is due to lower thermal conductivity of spinel bricks (≈ 3 W/m.K) as compared to MgO-C bricks (≈ 10 W/m.K).
- Spinel linings are more reliable in terms of safety as compared to conventional unfired products because any defects or intrusions will be surfaced out during high temperature firing process itself.
- Environment friendly refractories. Push to ecofriendly environment. Spinel bricks material is recyclable.
- Boost to refractories based on indigenous raw materials and reduce dependence on imported magnesia raw materials mainly sourced from China.
- Reduction in inventory and improved inventory management by having local sources & also optimization of working capital & bank limits etc.

Alumina-Magnesia spinel bricks are developed with special characteristics such as volume stability during application, better spalling resistance, less slag penetration, and improved slag corrosion resistance. A-M spinel bricks were installed in 130 and 180 MT capacity ladles in one of the largest integrated steel plants in India. Performances are encouraging as per below details.

Spinel Product Information:

We developed alumina spinel bricks with desired chemical and physical properties as mentioned in Table 1.

Table1: Typical Properties of Spinel brick:

Properties	Typical Value
Chemical Properties	
Al2O3 (%)	94.36
Fe2O3 (%)	0.21
SiO2 (%)	0.32
TiO2 (%)	0.02
MgO (%)	4.78
Na2O+K2O (%)	0.31
Physical Properties	
A.P. (%)	15.9
B.D. (g/cc)	3.10
CCS (kg/cm^2)	750
Other Properties	
Thermal Shock at 1350^{O}C (no of WQ cooling Cycles)	7
HMOR at 1400^{O}C (kg/cm^2)	95.8
PLC at 1600^{O}C/ 5hrs (%)	+ 0.06
RUL (t_a ^{O}C)	1720 (ND)

Applications and Case Study:

A. Performance and Specific Consumption:

Alumina Spinel bricks used in ladles each with capacity of 130MT, 180MT & 350MT respectively. The lining pattern is followed as per the existing practice in the steel plants.

Table2: Spinel bricks performance compared with MgO-C bricks:

Description →	Ladle Bricks Life MZ+BTM (Heats)		Specific Consumption for MZ+BTM (kg/TLS)		Carbon Pickup (ppm) during ladle refining	
Bricks Quality →	MgO-C	Spinel	MgO-C	Spinel	MgO-C	Spinel
Ladle Capacity – 130MT	140	195	0.95	0.60	NA	02-05 ppm
Ladle Capacity – 180MT	145	165	0.85	0.75	NA	02-05 ppm
Ladle Capacity – 350MT	90	110	NA	1.15	NA	NA

B. Energy Savings / Heat Losses:

There are heat losses from the refractory linings due to heat transfer from hot refractory linings to the ladle shell. We have monitored shell temperatures throughout the campaign and observed that heat losses from the shell in Spinel working linings are less as compared to MgO-C working lining. Table 3 below are the readings of shell temperatures of 350T steel ladle with working lining of spinel bricks at Bottom & Metal Zone and Mag-Carbon lining at Slag Zone.

Table2: Shell Temperatures at Spinel & MgO-C bricks zone wise:

LADLE LIFE (Heats)		Shell Temperatures at Zone wise Refractory Lining Life					
		Bottom		Metal Zone		Slag Zone	
MZ	SZ	Impact	Non-Impact	Purging1	Purging2	Purging1	Purging2
0	0	121	119	119	122	144	154
0	0	129	115	125	133	145	146
1	1	146	138	169	157	194	201
11	11	174	169	171	158	191	171
22	22	194	180	180	168	190	205
35	35	217	195	187	181	202	204
40	40	207	185	176	186	199	206
45	45	215	196	197	202	225	218
80	36	228	202	209	218	228	220
95	49	235	211	227	221	256	264

Conclusions:

Alumina spinel bricks successfully developed to achieve higher performances and minimum or no carbon pick up from the working lining in steel ladles. Indigenously developed Spinel-bricks will be the cost effective solution for steel ladles Metal zone and Bottom linings with reduced specific consumption of refractories and energy saving on account of less heat losses.

Make in India "new generation refractories" enabled Indian refractory producers to enhance the product range with those superior quality new generation refractory products. India is heading towards reducing dependence of China for FM & DBM based refractories.

Made in India, MgO-C & AMC products are performing up to bench mark levels in steel ladles up to 350T capacity and improving further. Also superior quality EAF MgO-C bricks have achieved satisfactory results in 100T capacity EAF's. Al_2O_3-SiC-C (ASC) bricks developed in India have performed above satisfactory levels.

REFERENCES:

- "Recent progress of steel making tech. and expectation for refr." ; Taikabutsu Overseas6,18-36,(1886) - N.Moritama,
- Chapter-3 Steel Plant Refractories – The AISE Steel Foundation, Pittsburgh Copyright©1999 - D.H. Hubble
- Almatis: Complete Alumina Expertise – Iron & Steel Review – January – 2013 – Vol 56 No.8
- Development of high performance spinel brick for steel ladle applications – Proceeding 162 – UNITECER 2015 – 14th Biennial Worldwide Congress -J.P.Nayak, B. Ghosh, K. Tsuyuguchi, P.B. Panda, S. Chatterjee
- "Global and Indian perspectives of alumina-spinel lining concepts in a steel ladle"; Proceedings UNITECER 2019: Andreas Buhr, Almatis GmbH; Atanu Ranjan Pal, Brijender Singh, Prasanta Panigrahi, Tata Steel, India; Jerry Dutton Stourbridge,UK;
- www.worldsteel.org
- Refractories for steel secondary metallurgy. CN-Refractories 6 (1999) [3] 19–30 [3] Quintela, M.A.; et al.: Refractories selection for steel ladles. Proc. UNITECR 2005, Orlando, USA: [2] Buhr, A.
- "Spinel: In situ versus preformed – Clearing the myth"; refractories worldforum 2 (2010)[87-93] by M. Schnabel; A. Buhr; R. Exenberger; C. Rampitsch;
- "Effectiveness of fired alumina-spinel brick in secondary metallurgy" Proc. UNITECER 2017 - Shankha Chatterjee1, Dr Andreas Buhr2, Rainer Kockegey-Lorenz2, Dr Atanu Ranjan Pal3, Brijender Singh3
- www.steel-360.com/stories/steel/application-refractory-steelmaking-January 2017
- "Technical development of refractories for steelmaking processes"; Nippon steel technical report no.98 July 2008 by Satoru ITO, Takayuki INUZUKA – Technical report;
- www.mordorintelligence.com/industry-reports/refractories-market
- www.refractories-worldforum.com 2009-2021

Effect of fume silica reduction on the properties of alumina magnesia castable

Satyam Kumar[1, a] and Ritwik Sarkar[2]

[1,2] *Department of Ceramic Engineering, National Institute of Technology, Rourkela, Odisha-769008, India.*

[1, a] Corresponding author's email: satyamk19@gmail.com

Abstract

This paper focuses on the properties of alumina magnesia-based based castable considering two different particle size distributions 0.21 and 0.29 with the reduction in fume silica content from 4 wt.% to 1 wt.%. Alumina magnesia-based castable compositions were processed as per conventional processing technique and further evaluated for physical, mechanical, and thermomechanical properties at 110, 1000, and 1550 °C temperatures respectively. The result showed that in comparison to 4 wt. fume silica % content;1wt.% fume silica addition leads to an improvement in castable mechanical and hot strength properties. A phase analysis study shows the presence of a low melting anorthite phase formation with 4 wt.% fume silica content. Microstructural and energy dispersive analysis of alumina magnesia castable fired at 1550 °C shows that the glassy phase is present in 4 wt.% fume silica addition however hibonite phase is formed with 1 wt.% fume silica content.

Keywords*:* Alumina magnesia castable, calcium hexa aluminate, Hot strength; Properties

INTRODUCTION

Industrial sectors nowadays are trying to increase energy performance by lowering costs and reducing environmental impacts [1]. Higher thermal energy is required to operate the equipment inside these industries, typically heated at around 1500 °C and 815 °C [2]. These benefits can be taken by employing improved refractory materials, which can withstand a higher number of runs, and lesser maintenance required, or it can be a replacement for new ceramic linings. The development of refractory material with suitable thermomechanical properties in a broad range of temperatures [3, 4] is of utmost importance as many industries operate at lower than steelmaking temperatures.

Refractory lining in the ladle prevents the steel vessel from being damaged during transportation and holding from molten steel and slag. Improving the ladle's performance not only reduces the cost of production but also helps in reducing the erosion and corrosion of refractories. Ladle refractories are divided into four zones: slag zone, sidewall, well block, and bottom [5]. The requirements for various zones of steel ladle are different, the right kind of refractories in each zone is necessary to achieve better performance and longer service life. Magnesia carbon refractories are preferred in the slag zone due to their excellent corrosion and thermal shock resistance [6-8]. Again, the steel ladle requirements for the sidewall portion are relatively different from that of the bottom part. Alumina magnesia castable (forming in-situ spinel) is used in the sidewall portion of the ladle [9-13]. These castables are essential for the sidewalls below the slag line to reduce the corrosion and erosion of refractories, reduce labor costs, improve service performance and life, and produce good quality steel [14-17].

The present work investigates the effect of fume silica reduction in alumina magnesia (forming insitu spinel) castables with varying MgO content 2.8 and 5.6 wt.% with two different particle size distribution coefficients, q = 0.21 and 0.29, as per Dinger and Funk model. Present work uses same grade of raw materials in castable making & it is processed precisely under similar conditions. Final properties are evaluated after heat treatment at temperatures of 110,1000, and 1550 °C.

2. Experimental procedures:

The Alumina magnesia based castables were formulated on the basis Dinger funk equation and considering the distribution coefficient values (0.21 and 0.29 [18], (Table 1). The initial raw material used in this study is white tabular alumina of different grades (WTA), fine alumina(RA), fume silica as a flow modifier, and calcium aluminate cement (CA14M Almatis, India) as the binder. Table 2 shows the physicochemical properties of raw material used in this castable-making process. Fume silica 4 wt.% and 1wt.% were varied according to the batch composition with two different distribution coefficient q values 0.21 and 0.29. Darvan-c as a dispersant 0.3 wt.% was added to the dry-powders before the mixing step. Citric acid as set retarder 0.1 wt.% was used. The mixing process was done in Hobart mixture initially dry mixing for (4 to 5) minutes then water is added gradually in the system to attain proper flow condition. All the castable compositions were prepared in a cube mold of 25×25×25 mm. Samples curing was done in humid conditions at 32 °C for 24 hours. The top surface of the samples was covered with wet clothes to maintain a uniform temperature on the top and bottom surfaces of the casting. Castables samples were demoulded, dried in air for 24 hours, dried in the oven at 110 °C for 24 hours, and fired at 1000 and 1550 °C. Physical properties such as bulk density (B.D) and apparent porosity (A.P) were measured at 110,1000, and 1550 °C by Archimedes principle using the liquid displacement method. Cold crushing strength (CCS) and hot Modulus of Rupture (HMoR) tests of the dried and fired specimens were carried out to investigate the effect of fume silica reduction in the prepared formulations. X-ray diffraction technique XRD techniques (Rigaku, Japan make) were used to determine the phase analysis of the powdered samples fired at 1550 °C using Cu Kα radiation through a Ni filter with a scanning rate of 5°/min in the range of 10-60 °. Microstructural investigation of fractured surface fired at 1550 °C was done in the scanning electron microscope and EDS analysis.

Table 1. Batch formulation with 4 and 1 wt.% fume silica content:

Material/ Batch (q value)	1	2	3	4	5	6	7	8
	.21	.29	.21	.29	.21	.29	.21	.29
WTA	70.8	77.0	70.8	77.0	70.8	77.0	70.8	77.0
Fine alumina	17.9	11.7	15.1	8.94	20.9	14.7	18.1	11.94
Fused magnesia	2.8	2.8	5.6	5.6	2.8	2.8	5.6	5.6
Cement	4	4	4	4	4	4	4	4
Fume silica	4	4	4	4	1	1	1	1
Dispersant	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Citric acid	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Water	8	7.2	8	7.8	8.4	8.2	8	7.8

Table 2. **Physio-chemical properties of raw materials**

Chemical analysis (in mass -%)	WTA	Fine Alumina	Fused magnesia	Fume-silica	High alumina Cement
SiO_2	≤ 0.09	0.03	0.4	98.1	0.3
Al_2O_3	99.5	99.7	0.07	0.4	71
Fe_2O_3	≤ 0.02	0.04	0.22	0.1	0.2
TiO2	-	-	Trace	-	-
CaO	-	0.03	1.4	0.2	28
MgO	-	-	97.35	0.1	0.4
$Na_2O + K_2O$	≤ 0.40	0.1	0.26	0.4	0.3
Particle size (D_{50} = μm)		2.5			
Bulk density (g/c)	3.61		3.58		
Apparent porosity (%)	3.98%		1.3		
Sp. surface area (m^2 /g)		3.1		20	0.44
Phase analysis	Corundum	Corundum	Periclase	Amorphous	CA_2, CA

3. Results and Discussion

3.1 Bulk density Study and Apparent porosity study:

Density values of magnesia based castable with 4 and 1 wt.% fume silica addition with MgO content 2.8 and 5.6 wt.% are shown in figure 1 & 2, respectively. The bulk density values of the batch composition lies in the range of 2.8 - 3.1 g/cc.

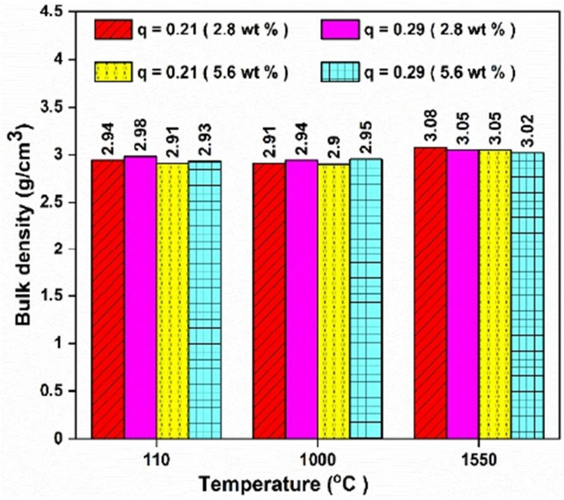


Figure 1. Bulk density variation with 4 wt.% fume silica

The bulk density value of 4 wt.% fume silica batch composition is higher than 1wt.% fume silica at peak temperature for all the q values. The Bulk density value decreases with an increase in MgO content from 2.8 to 5.6 wt.%. It may be due to replacing the higher-density material with lower density. The no of fine content is higher for the batches with distribution value q =0.21, which allows more sintering and densification than distribution coefficient values of 0.29. Figure 3 and 4 represent apparent porosity values of 4 and 1 wt.% fume silica content in alumina magnesia castable composition. Apparent porosity values are in accordance with bulk density values. The apparent porosity value for 1 wt.% fume silica batch composition at elevated temperature is higher than 4 wt.% fume silica content due to its lower bulk density value. At intermediate temperature, the apparent porosity value increases; it decreases at elevated temperature. An opposite trend is observed due to spinel formation and sintering occurring simultaneously at a higher temperature.

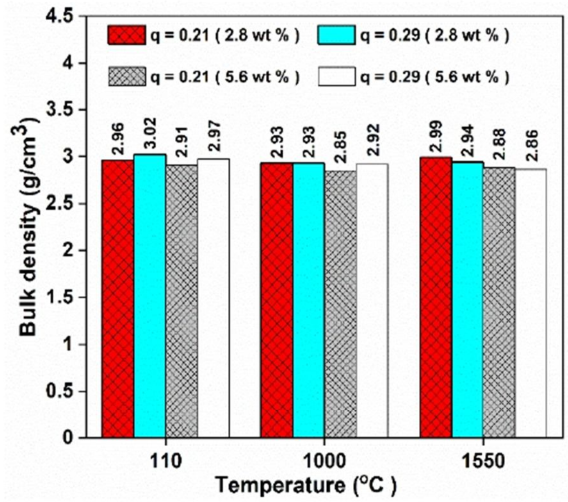


Figure 2. Bulk density variation with 1 wt.% fume silica

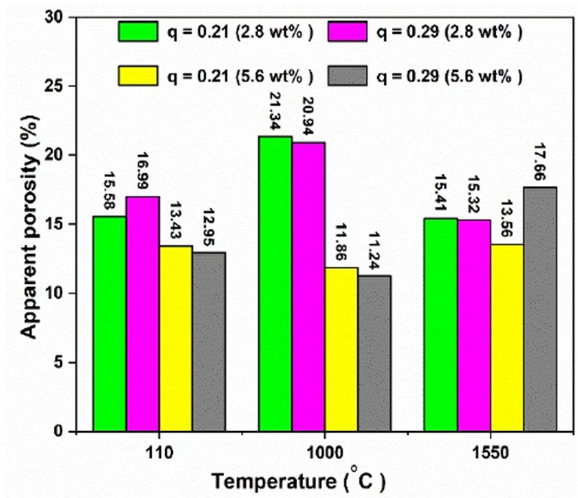


Figure 3. Apparent porosity variation with 4 wt.% fume silica

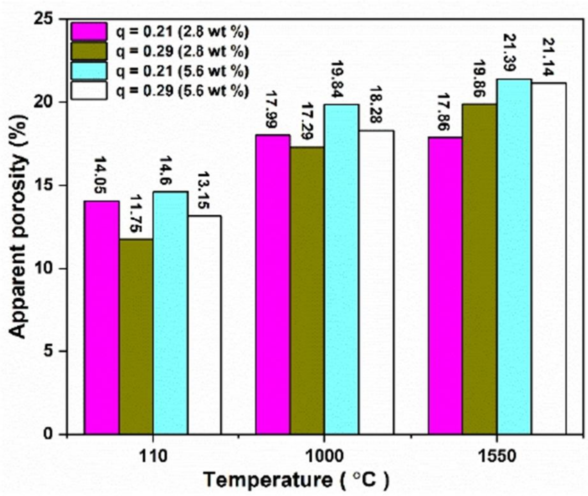


Figure 4. Apparent porosity variation with 1 wt.% fume silica

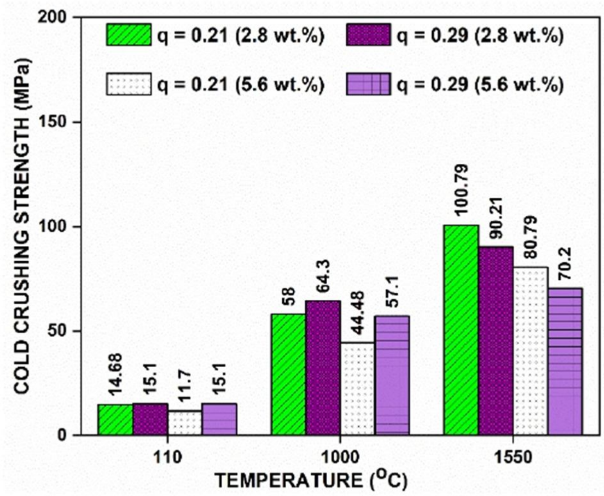


Figure 5. cold crushing strength study with 4 wt.% fume silica

3.2 Strength study:

The strength of a castable composition mainly depends on two factors (i) porosity removal of physically and chemically bonded water and (ii) sintering at a higher temperature. Figure 5 and 6 represents the cold crushing strength value with 4 wt.% fume silica and 1 wt.% fume silica content, respectively, with two different particle size distribution. Cold crushing strength value not degraded with the removal of physically and chemically bonded water at 1000 °C. At peak temperature strength value is higher with 1wt.% fume silica content with particle size distribution q = 0.21. High MgO content has also reduced the strength value due to more spinel formation in both 4 and 1 wt.% fume silica batches. The effect of the q value is observed more prominently at temperatures of 1550 °C. Lower q values have a larger percentage of finer fraction, resulting in better densification due to sintering.

3.3 Phase analysis:

Phase analysis study of matrix part with 4 wt.% and 1 wt.% fume silica containing batches was done by powder X-ray diffraction techniques (XRD) at temperatures 1550 °C with two different q values 0.21 and 0.29.

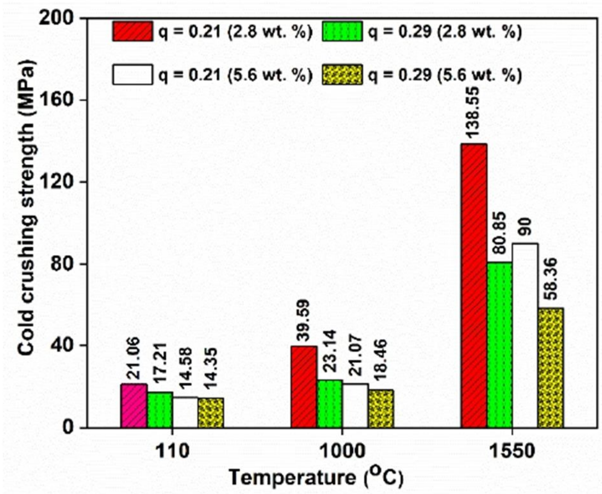


Figure 6. cold crushing strength study with 1wt.% fume silica

Figure 7 -10 represents xrd pattern of 4 and 1 wt.% fume silica content in alumina magnesia castable composition. Matrix part is only considered for phase analysis as spinel reacts only in the matrix phase. Phase analysis shows a sharp crystalline structure with alumina and spinel as a significant phase in both the 4 wt.% and 1 wt.% system. There is no variation seen with respect to the q value. Lime bearing phase anorthite was seen with 4 wt.% fume silica;

however, fume silica is reduced to 1 wt.% hibonite phase observed along with diopside, and some traces of MgO. The Hibonite phase is desired refractory phase due to its plate-like morphology, and it can improve refractory properties like thermal shock and corrosion resistance.

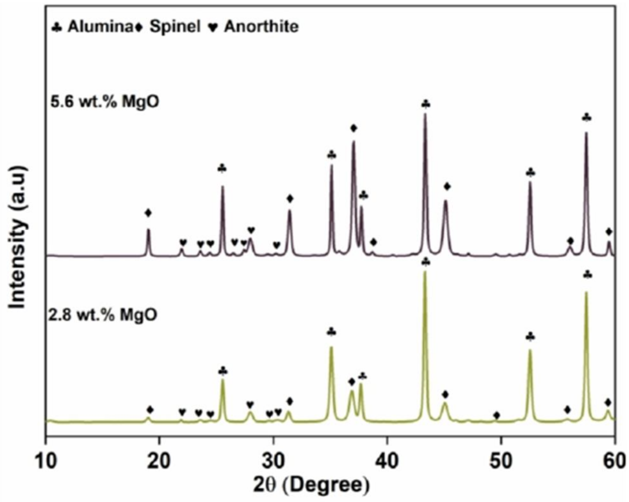


Figure 7. phase analysis of matrix part with 4wt.% fume silica and q=0.21

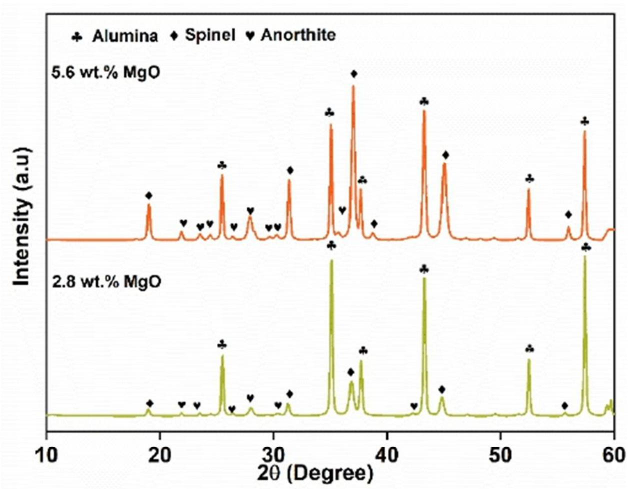


Figure 8. phase analysis of matrix part with 4wt.% fume silica and q=0.29

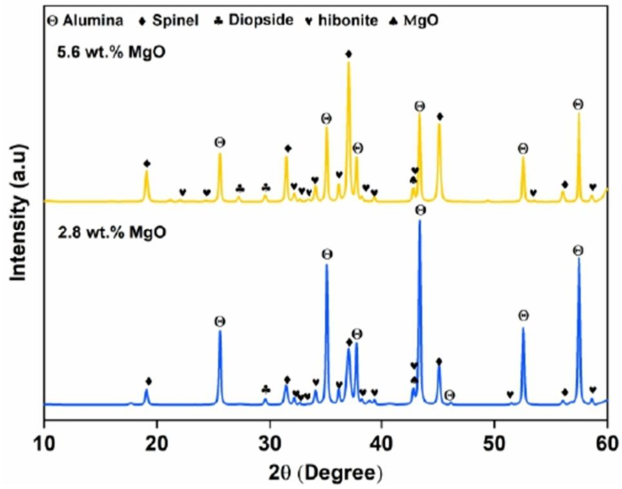


Figure 9. phase analysis of matrix part with 1wt.% fume silica and q=0.21

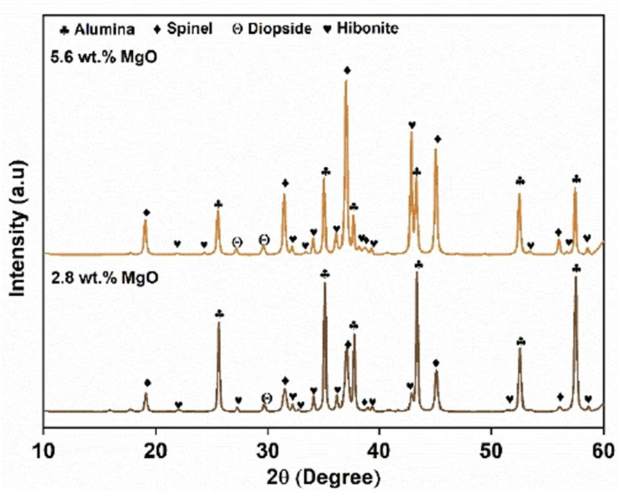
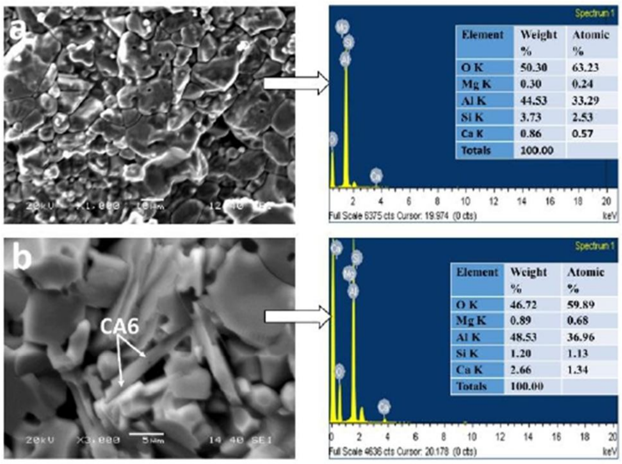


Figure 10. phase analysis of matrix part with 1wt.% fume silica and q=0.29

3.4 Microstructural study:

Micrographs of alumina magnesia castable batches with fume silica content of 4 wt.% and 1 wt.% are shown in figures 11(a &b). Micrographs show grains are polyhedral with compact packing, resulting in better densification. Energy dispersive X-ray analysis confirms oxygen(O), aluminium(Al), calcium (Ca), and silicon (Si) elements present in the system, which is also supported by phase analysis. Hexagonal plate-like morphology is observed with 1 wt.%

fume silica content, which is calcium hexa aluminate. This phase helped in better interlocking structure between matrix and aggregate phase. Some pores are also observed inside the grain



boundary.

Figure 11 (a & b). Micrographs of alumina magnesia castable batches with fume silica content of 4 wt.% and 1 wt.%

3.5 Hot strength study:

Hot strength study of alumina magnesia batch composition with 4 and 1 wt.% fume silica addition represented in figure 12 with varying MgO content 2.8 and 5.6 wt.%. Reduction in fume silica content has improved the hot strength value. Phase analysis study shows the formation of low melting phase anorthite in the system, which was responsible for decreasing hot strength value; however, in 1 wt.% fume silica containing batches, anorthite phase was not seen, but the hibonite phase was observed. This phase helped in improving the hot strength property in the system. Moreover, increasing MgO content shifts the castable composition toward ternary eutectics in Al_2O_3-MgO-SiO_2 system and also decreases the hot strength value.

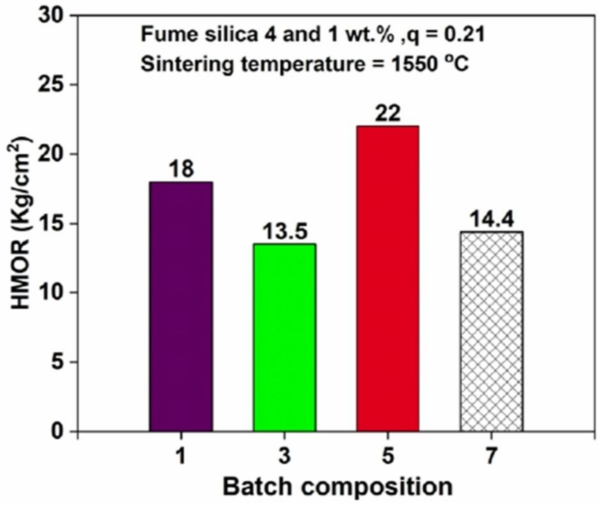


Figure 12. Hot strength of the batch composition

4.Conclusion:

Alumina magnesia castable (insitu based) with 2.8 and 5.6 wt.% MgO addition was studied by varying 4 wt.% and 1 wt.% fume silica with two different particle size distributions. The following conclusion can be drawn:

- The bulk density value is higher with 4 wt.% fume silica content for both q values 0.21 and 0.29.
- Cold crushing strength value is higher for 1 wt.%. fume silica batches with MgO addition 2.8 wt.% with a distribution coefficient value of 0.21.
- A low melting anorthite phase was observed with 4 wt.% fume silica addition, but the hibonite phase was observed with 1 wt.% fume silica content.
- Micrographs study shows platy-like crystal structure with 1 wt.% fume silica batches.
- The system has a lower hot strength value with higher fume silica content due to low melting phase formation.

Refrences:

[1] E. A. Abdelaziz, R. Saidur and S. Mekhilef, "A review on energy saving strategies in industrial sector," *Renewable and sustainable energy reviews*, vol. 15, no. 1, pp. 150-168, January 2011

[2] L. B. Consonni, A. P. Luz and V. C. Pandolfelli, "Binding additives with sintering action for high-alumina based castables," *Ceramics International*, vol. 45, no. 12, pp. 15290-15297, August 2019.

[3] A. P. Luz, A. S Neto, T. Santos. Jr, J. Medeiros, V. C. Pandolfelli, "Mullite-based refractory castable engineering for the petrochemical industry," *Ceramics International*, vol. 39, no. 8, pp. 9063-9070, December 2013.

[4] A. P. Luz, A. H. Gabriel, L. B. Consoni, C. G. Aneziris and V. C. Pandolfelli, "Self-reinforced high-alumina refractory castables," *Ceramics International*, vol. 44, no. 2, pp. 2364-2375, Feburary 2018.

[5] P. Tassot, P. Andres, T. Schemmel and P. P Sobarzo, "Evolution of the steel ladle refractories lining in last decade," In: *47th Steelmaking Seminar - International,* Rio de Janeiro, vol. 47, no. 47, pp. 128-137, September 2016.

[6] T. Matsui and N. Taki, "Refractory technology of ladle," *Nippon Steel Technical Report*, vol. 415, pp. 52-55, 2020.

[7] Ishikawa, Akira, M. Sato, and T. Kanai, "Improvement of siderwall castable for steel ladles at Kashima Steel Works," *In proceeding*: *Unitecr*, pp. 121, 2017.

[8] Q. Chen, Y. Li, T. Zhu, Y. Xu, Y. Li, X. Wang, "Improved thermal shock resistance of MgO–C refractories with addition of calcium magnesium aluminate (CMA) aggregates," *Ceramics International*, vol.48, no. 2, pp. 2500-2509, January 2022.

[9] M. Schnabel, A. Buhr, R. Exenberge, C. Rampitsch, "Spinel: in-situ versus preformed-clearing the myth," *Refractory World forum*, vol.2, no.2, pp. 87-93,2010.

[10] A. Huang, Y. Wang, Y. Zou, H. Gu and L. Fu, "Dynamic interaction of refractory and molten steel: corrosion mechanism of alumina-magnesia castables," *Ceramics International*, vol. 44, no.12, pp. 14617-14617 24, August 2018.

[11] H. Tang, C. Li, J. Gao, B. Touzo, C. Liu and W. Yuan, "Optimization of properties for alumina-spinel refractory castables by CMA (CaO-MgO-Al_2O_3) aggregates," *Materials*, Vol. 14, no. 11, pp. 3050. June 2021.

[12] X. Li, J. Li and L. Zhang, "Enhancing mechanism of improved slag resistance of Al2O3-spinel castables added with pre-synthesized $(Al,Cr)_2O_3$ micro-powder," *Ceramics Interntional*, vol. 47, no. 23, pp. 33322-333299, December 2021.

[13] W. Yuan, H. Tang, H. Shang, J. Li, C. Deng and H. Zhu, "Effects of TiO_2 addition on kinetics of insitu spinel formation and properties of alumina-magnesia refractory castables," *J.Ceram.Sci.Technol.*, vol. 8, no. 1, pp. 121-127, March 2017.

[14] D. Zhang, C. Li, N. Jiang, J. Gao, B. Touzo and W. Yuan, "Influence of powder characteristics of reactive alumina on properties of alumina-spinel castables," *Ceramics International*, vol. 44, no. 8, pp.9984-9984, June 2018.

[15] Y.C. Ko and C. F. Chan, "Effect of spinel content on hot strength of alumina-spinel castables in the temperature range 1000–1500 °C," *Journal of the European Ceramic Society*, vol. 19, no. 5, pp. 2633-2639, November 1999.

[16] M. Fuhrer, A. Hey and W.E. Lee, "Microstructural evolution in self-forming spi-

nel/calcium aluminate-bonded castable refractories," *Journal of the European Ceramic Society*, vol. 18, no. 7, pp. 813-820. January 1998.

[17] Y. Cheng, Y. Zhang, Y. Li, J. Chen, J. Xiao, Y. Wei, G. Liu, G. Li, S. Zhang and N. Li, "Degradation behaviors of cement-free corundum-spinel castables in Ruhrstahl Heraeus refining ladle: Role of infiltrated steel," *Ceramics International*, vol. 47, no. 22, pp. 32008-32014, November 2021.

[18] D. R. Dinger and J. E. Funk, "Particle packing. III: Discrete versus continuous particle sizes," *Interceram*, vol. 41, no. 5, pp. 332-334,1992.

Alumina Rich Spinel Refractories for Steel Ladle Application – A Complete Solution by TRL Krosaki

J. P. Nayak*, R. Dutta, B. Ghosh, P. B. Panda

TRL Krosaki Refractories Limited, Belpahar -768 218, Odisha (India)
Corresponding Author's email: jyoti.nayak@trlkrosaki.com

ABSTRACT

Demand and uses of alumina rich spinel bricks for steel ladle application is increasing day by day because, demand of ultra-low carbon Interstitial-Free (IF) grade steel increases extremely in the market. Till date, with the technological evolution, alumina rich spinel fired bricks are found suitable in metal zone application of steel ladle for IF grade steel production. Currently, fired spinel brick is being preferred by steel manufacturer to use in place of alumina-magnesia-carbon (AMC) for bottom application of steel ladle due to carbon footprint issue. However, magnesia-carbon (MgO-C) brick has retained its position for slag band of steel ladle due to its special characteristics, and moreover unavailability of any alternative refractory solutions till now. Due to heterogeneous refractory lining system, operational severity; performance of steel ladle puts a great challenge before steel manufacturer with respect to campaign life, cost, and time. However, TRL Krosaki (TRLK) has already mitigated these challenges related with steel ladle by developing zone wise different suitable grade of refractories for steel ladle application. All these products are performing well at different customer end with enhancement of ladle life.

Keywords: steel ladle, refractory brick, alumina, spinel, carbon

INTRODUCTION

Steel ladles are used in manufacture of ultra-low carbon Interstitial-Free (IF) grade steel. Several crucial parameters like; increasing tapping temperature, longer holding time, purging and secondary metallurgical refinement are countered by the different types of refractory materials used in various areas of the ladles to achieve longer life [1,2]. Since, different quality of refractories is being lined; different wear mechanisms exist in various areas/zones within a steel ladle. Mainly there are 3-different zones in a steel ladle, (i) Bottom, (ii) Metal Zone, and (iii) Slag zone. Magnesia carbon bricks are often used in slag zone (S/Z), alumina rich spinel burnt bricks in metal zone (M/Z) typically refers to the area of the ladle sidewall that is below the slag line, the area which remains contact with the hot molten steel when ladle is filled to the capacity, and Alumina-magnesia-carbon or alumina rich spinel burnt bricks are used in bottom of the steel ladle. Magnesia-carbon bricks exhibit significantly better slag resistance and Alumina-magnesia-carbon bricks show better erosion resistance with less subject to attack of the brick joints compared to burnt alumina bricks [3-5]. However, to suppress carbon pick up by steel from hot liquid metal; the decision of using alumina rich spinel burnt bricks in M/Z is being dictated by many factors.

Spinel being a defect structure; Fe^{2+} and Mn^{2+} ions from the liquid slag is being accommodated in spinel structure, as result, slag becomes more viscous and hence less penetrative towards the matrix of alumina rich spinel bricks during steel ladle operation. Due to presence of spinel, also hot strength of spinel burnt quality brick increases.

Although steel ladle refractories are chemically pure but exhibit different thermo-physico properties due to combination of different refractory raw materials in a single refractory product. In case of MgO-C refractory; both thermal conductivity and thermal expansion value is more compared to Al_2O_3-Spinel product. On the other hand, density of Al_2O_3-spinel refractory is more than MgO-C brick. Thus, in steel ladle application, in slag and metal zone interface; there is mismatch of thermal gradient, thermal expansion ratio and different characteristics towards slag attack. Hence, there is a desire to minimize the differences of all Thermo-physico properties of refractory lining between M/Z and S/Z interface area of steel ladle to improve the ladle life further.

Types of Spinel Products for Steel Ladle Application

Apart from MgO-C and alumina magnesia carbon (AMC) refractory products; TRLK is manufacturing both fired and baked alumina rich spinel products for steel ladle application. Table 1 summarizes the properties of spinel products.

Properties	Fired Spinel Brick	Baked Spinel Product
AP (%)	16.7	5.6
BD (g/cc)	3.13	3.21
CCS (kg/cm^2)	570	663
RUL (t_a) °C	1750+	1750+
PLC at 1450°C/ 2hrs. (%)	+0.05	+0.14
HMoR at 1500°C (MPa)	4.5 – 6.8	2.9 - 4.4
Spalling Resistance	****	***
Slag Corrosion Resistance	***	*****

Both fired and baked products are manufactured with high intensity inclined mixer machine (EIRICH), high-capacity automatic hydraulic press (1600T), long tunnel dryer, high temperature tunnel kiln and long tempering kiln. Slag corrosion test has been carried out using Induction furnace slag corrosion test method at 1600°C with 1 hour soaking. From slag corrosion study it is observed that both quality is showing excellent slag corrosion resistance, but baked spinel product is resulting quite good result due to presence of optimized quantity of graphite and special type of antioxidant in the system. Due to presence of carbon in baked product, which leads to non-wetting characteristics towards molten metal and during prolong operation of steel ladle, Al_4C_3 phase might be developed in the system, and corrosion resistance is improving significantly. Thermal spalling test with water quenching method (DIN 51068) of both products resulting very good results but fired spinel product is showing better than baked one due to presence of graphite in baked spinel brick system.

Now a days, steel manufacturers are preferring to use these spinel products for steel ladle application to achieve hassle free operation with expected campaign life. In general practice, MgO-C refractory used in S/Z area, alumina rich fired spinel brick is used in M/Z area, and AMC or fired spinel quality brick in bottom area of steel ladle. Fig.1 shows the refractory lining pattern of steel ladle of a major iron & steel producer in India.

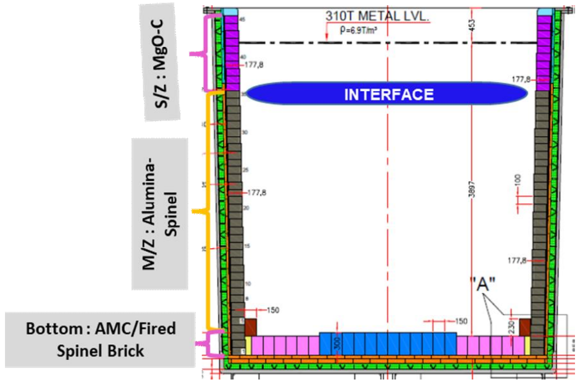


Fig.1: Refractory lining pattern of Steel Ladle.

It is observed that due to use of heterogeneous refractory lining system; interface area of steel ladle becomes weak which leads to low ladle life. The major reasons of weakening the interface area are mismatch of thermal gradient, mismatch of thermal expansion ratio leads to stress development, susceptible area to generate low contact angle by molten material and vulnerable area for development of eutectic phases. Interface area of steel ladle the active film motion is dominantly induced by the Marangoni effect and change in the form of slag film due to the variation of the surface tension and the density of slag film. Also, it has been seen that steel ladle having two purging systems aggravates the interface more compared to ladle of single purging system due to development of bigger slag-eye, model shown in Fig.2. However, by using TRLK made baked alumina rich spinel product in interface or transition zone of steel ladle, enhances the ladle life further (Fig.3).

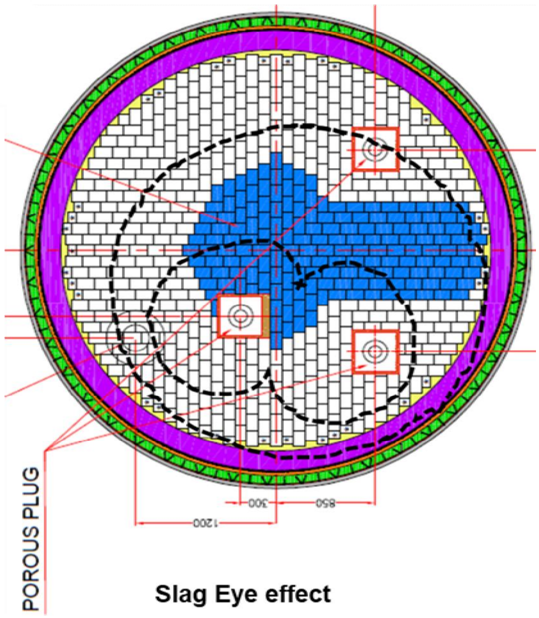


Fig.2: Model representation of Slag-eye in Steel Ladle.

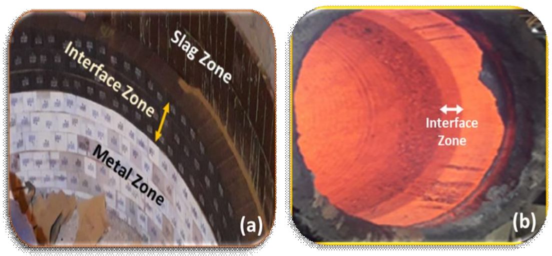


Fig.3: (a) Different quality refractory lining of Steel ladle, (b) Interface refractory condition after 100+ heats of steel ladle.

CONCLUSION

By using baked alumina rich spinel brick in interface area (transition zone) of S/Z and M/Z of steel ladle, thermal gradients between MgO-C and fired spinel brick is reduced. Baked spinel refractory is minimizing the wide difference of thermal conductivity, modulus of elasticity, and refractoriness between S/Z and M/Z refractories lined in steel ladle. By using baked alumina spinel brick in interface area; both Marangoni and Slag-eye effect also suppressed in steel ladle, as a result ladle life enhances further.

REFERENCES

[1] K. SUGITA, "Historical overview of refractory technology in the steel industry", Nippon steel technical report no.98, 8-17, (2008).

[2] J. H. Chesters, "Steelplant refractories", United steel Co. 1944.

[3] W.E.Lee and R.E.Moore, "Evolution of in situ refractories in the 20th century", J. Am. Ceram. Soc. 81, 1385-1410, (1998).

[4] S.K.Chen, M.Y.Cheng, S.-J.Lin and Y.C.Ko, "Thermal characteristics of Al_2O_3–MgO and Al_2O_3–spinel castables for steel ladles", Ceramics International, 28, 811-817, (2002).

[5] S. Dudczig, G. Schmidt, C. G. Aneziris, C. Wohrmeyer, C. Parr, P. Gehre, "Corrosionof MgO-C with Magnesium Aluminate Spinel addition in a steel casting simulator", Ceramics, *3*(1), 12-21 (2020).

Co-relation of various refractory & operational parameters on the steel ladle life of ISP.

M. Bose[1,2], Prasanta Baidya[1] B K Sinhamahapatra[1], Tarun Misra[1], V K Rai[1],
1. Refractories Department, 2. BOF-CCP shop, SAIL-IISCO Steel Plant, Burnpur – 713325, W.B.
2. Corresponding Author's e-mail: malancha.bose@sail.in

Abstract

ISP is an integrated steel plant in SAIL family with a production capacity of 2.5 million tons of crude steel which comes from 3 converters with a capacity of 150 MT each. Liquid Steel is poured from BOF, refined in secondary refinery unit and finally transported to the casting units via steel ladles. Currently ISP has fleet of total 23 steel ladles with a capacity of 150 MT each out of which 10 ladles remain in circulation on an average. Steel ladle performance plays an important role as production of steel is directly dependent on its performance. The only way to reduce the cost is to increase the life of steel ladle. Refractory team of ISP has studied the scopes of various refractories in its steel ladles like MgO-C bricks, Dolomite bricks, Spinel Bricks etc. to maximize its ladle life. Apart from that Refractory team has also analyzed the operational parameters like Slag chemistry, metal holding time, Arcing time, number of heats per day etc. for adapting best practices to get maximum output from its steel ladles.

Keywords – Steel ladle; Magnesia-Carbon Bricks; Ladle Furnace(LF); Empty time, Arcing time

INTRODUCTION

Steel ladle plays an important role in the metallurgical industry. It is used for storing and transferring of molten steel and its service life has direct impact in the normal production and cost of organisations. These days Steel ladle is used in significantly more complex manner. Other Functions carried out in the ladles are deoxidation, temperature control, additions of ferro-alloys and carburizer. In recent days, the demand has increased considerably for various grades of steel with stringent specifications. These steels are produced in secondary refining processes route. The lining of the ladles must withstand increasingly severe operating conditions associated with secondary refining processes. These severe conditions are higher liquid temperature, longer holding time, and arcing/chemical heating. Inert gas rinsing and degassing of liquid steel, alloying process and use of synthetic slag also accelerate the wear of ladle lining.[1], [2] Hence operating parameters has a significantly high influence on the lining performance of the steel ladle. In the year 2021-22, nearly 48% of the total refractory cost of SAIL-ISP was spent on steel ladles. The kg/tcs of steel ladle for 2019-20, 2020-21 and 2021-22 were nearly 42.3%, 40.6% and 39% respectively of the total specific refractory consumption of ISP.

CURRENT PRACTICE OF REFRACTORY LINING IN STEEL LADLE IN SAIL-ISP

Metal holding capacity of steel ladle at SAIL-ISP is 150 tonnes. Steel making process route is basic oxygen furnace (BOF), ladle furnace (LF) and caster. After BOF operation, steel is poured into steel ladle for further metallurgical operations at ladle furnace. Steel temperature varies from 1650°C to 1700°C at the time of tapping from converter to preheated ladle. During tapping fluxing agents are added for slag formation. Ladle goes to ladle furnace for reheating and final alloying during secondary steel making. Vigorous chemical reactions and heat treatment takes place at ladle furnace. Ladle is divided into two zones- slag zone and metal zone. At ISP, the steel ladle has 3500 mm available height after refractory lining, out of which the 2200 mm from bottom form the metal zone and remaining1300 mm form the slag zone. The steel ladle has 3 linings- namely working lining, and two numbers of safety/backup lining. Ceramic fibre board and high alumina castable are used in first safety lining adjacent to the shell (supported by anchors) as it has long life and high strength (high penetration resistance) and prevents heat loss. The second safety lining is done using magnesia-chrome/magnesite bricks and mortar. The working lining is done using Magnesia-Carbon (MCB) bricks both in slag and metal zone, with thickness of 178 mm in the metal zone and 200 mm in the slag zone. The bottom impact zone is lined with Alumina-Magnesia-Carbon (AMC) bricks. Functional refractories are two numbers of purging system and one slide gate system. Magnesia-Carbon refractories have excellent chemical and thermos-mechanical properties like corrosion resistance, thermal shock resistance, high hot strength etc., which makes them the most suitable refractory for steel ladle lining. The Alumina-Magnesia-Carbon bricks are based on alumina-carbon bricks that have magnesia as additive. When used in ladle and during operation, spinel forms to ensure residual thermal expansion. This expansion of the bricks closes the joints of the bricks and reduces metal penetration. Degradation of refractory lining of the steel ladle results from the interactions with chemical, thermal and mechanical phenomenon. The factors influencing the life of the refractory lining are metal holding time, ladle empty time, tapping temperature, arcing time, slag basicity, no of heats per day per ladle, bottom purging etc.

PERFORMANCE/LIFE OF STEEL LADLE IN SAIL-ISP

Over the years with the increase of crude steel production at SAIL-ISP, steel ladle life has also increased. Currently production of crude steel is around 2.23 million tonnes and average steel ladle life is around 64 heats.

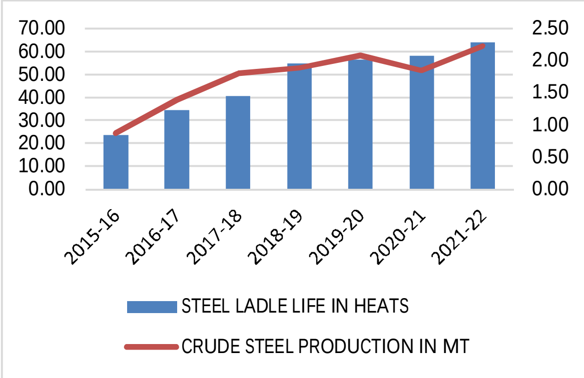


Fig. 1: Steel ladle life Vs Crude Steel Production in SAIL-ISP from the inception

DATA COLLECTION

Data of two phases: It is evident in the Fig. 1, that there is significant improvement in ladle life after 2020-2021. If we see the trend of monthly average life from April, 2020 to July 2022 (shown in Fig. 2), there are two stable phases of ladle life where there is an improvement of monthly average ladle life by approx. 15 heats. First phase from April 2020-

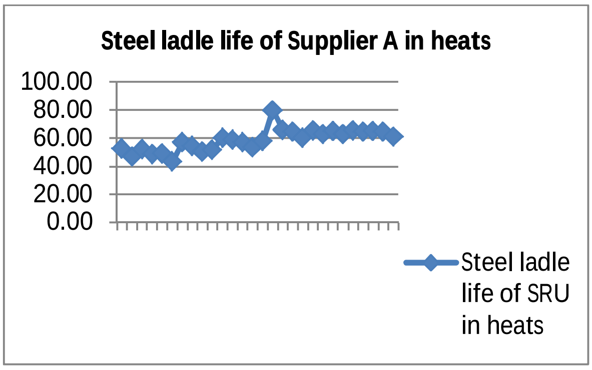


Fig. 2: Steel ladle life of Supplier 'A'

September 2020 (let be Phase X) where the average life is constant at around 50 heats and April 2022-August 2022 (let be Phase Y) where the life is around 65 heats. There is a transition phases in between from October, 2020 to March 2022. To identify the operating factors affecting the ladle life, data during Phase X and Phase Y have been analysed. To avoid any effect of variation in quality, ladles used of a particular supplier with consistency in supply and quality have been considered. Study conducted to find the co-relation between steel ladle life of the supplier 'A' with metal holding time, arcing time, turnaround time, LF slag basicity, no of heats per day per ladle, no of purging failures in the above mentioned two phases. In the phase April 20 – Sep 20, average steel ladle life of supplier 'A' is around 50 heats and in the next phase April 22 – August 22, average steel ladle life of the same supplier is around 65 heats. In these two-phase steel ladle lives was more consistent and there is significant improvement in the operational parameters from phase April 20 – Sep 20 to April 22 – August 22.

Metal holding time

	Ladle Life	Metal holding time in minutes	Arcing time in minutes	Empty Time
Phase X	49.02	179.48	17.44	187.65
Phase Y	64.50	140.19	16.76	126.65
% Change	31.59	-21.89	-3.86	-32.51

Table 1: Co-relation of steel ladle life with metal holding time in minutes, arcing time & empty time.

The count of Metal holding time starts from tapping of the converter. The metal holding time is the duration for which crude steel is present inside the steel ladle, that is, from the tap time to casting end time. During the metal holding time, the refractory lining is exposed to molten steel and slag during which refractory erosion can take place.

Arcing Time and Empty Time

Arcing time is the time for which temperature of liquid steel is increased inside the LF with the help of electrodes. During arcing, the high temperature is localized in the slag zone area, which results in the erosion of the refractory lining.

	Ladle Life	Metal holding time in minutes	Arcing time in minutes	Empty Time
Phase X	49.02	179.48	17.44	187.65
Phase Y	64.50	140.19	16.76	126.65
% Change	31.59	-21.89	-3.86	-32.51

Table 2: Co-relation of steel ladle life with metal holding time in minutes, arcing time and empty time.

Phase X		
Month	No. of heats per day per ladle	Empty time in minutes
Apr-20	4.14	203.50
May-20	4.00	183.96
Jun-20	4.41	178.11
Jul-20	4.17	208.86
Aug-20	4.20	169.73
Sep-20	3.92	181.76

Table 3: Empty time of steel ladle in FY 20-21

Phase Y		
Month	No. of heats per day per ladle	Empty time in minutes
Apr-22	5.00	141.38
May-22	5.06	137.51
Jun-22	5.31	109.59
Jul-22	5.03	120.53
Aug-22	4.94	124.26

Table 4: Empty time of steel ladle in FY 22-23

Empty time is the difference between the casting end time of the previous heat and the next tapping time of the ladle. After casting, ladle goes for slag dumping and after that it comes to ladle preparation stand. In ladle preparation stand, functional refractories are checked/changed as per requirement. After preparation the ladle goes for tapping. Reduction in empty time of steel ladle has significantly increased no of heats per day per ladle. Increase in no of heats per day per ladle is around 22% in Phase Y due to a reduction of empty time of 32%. Monthly average of steel ladle bottom purging failure in Phase X is 6.33 nos. whereas in Phase Y it has significantly reduced to 2.20 nos. which is a decrease of around 65%.

RESULTS & DISCUSSIONS

In iron and steel industries slag component has its major role due to its close contact with metal, refractories. Usually, they are solid solutions consisting of different oxides floating top of the steel. The primary functions of these oxides in the steel production are like covering of electrodes in the Ladle Furnace, inhibiting its oxidation and also protecting the refractories from thermal radiation, further protection of the liquid metal from oxidation, and to minimize heat loss. A suitable slag should have optimum viscosity to serve the above-mentioned purposes and save the refractory materials applied in the steel ladles. MgO–C bricks used in steel ladle to minimize slag attack during the operation and to adjust the liquid composition in order to attain slag saturation (mainly CaO and MgO) or at least the MgO. The MgO content required for liquid saturation depends on slag basicity and temperature. In the beginning of the process oxidation of carbon on the surface of the MgO-C lining takes place with oxygen present in surrounding gasses, dissolved oxygen and slag containing Mn and Fe oxides.[3]–[6] This wear mechanism primarily depends on slag chemistry, processing temperature and interaction time.

	Phase X	Phase Y
Ladle Life in heats	49.02	64.50
LF slag basicity mode	1.67	1.50
LF slag basicity mean	1.71	1.62
LF slag basicity median	1.71	1.59
LF slag basicity maximum	1.99	1.99
LF slag basicity minimum	1.17	1.35

Table 5: Study of LF slag basicity in Phase X and Phase Y

Study of the LF slag basicity data shows that in phase X mean, median, mode of LF slag basicity is 1.71, 1.71, and 1.67 respectively and in phase Y, it is 1.62, 1.59 and 1.5 respectively. In phase Y, minimum LF slag basicity data is 1.35 whereas in phase X it is only 1.17.

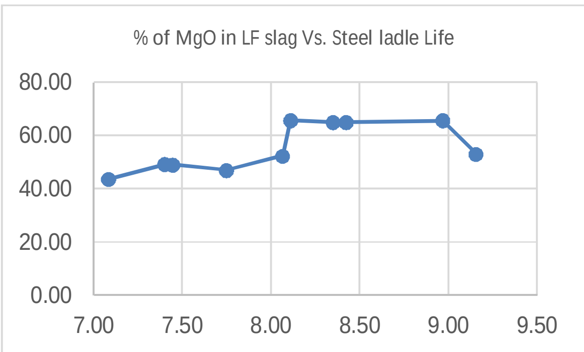


Fig. 3: Plotting of % of MgO in LF slag against steel ladle life in Phase X and Phase Y

The graph shows that when percentage of MgO in LF slag is in 8.07%-8.97%, steel ladle life is also in the best range but when percentage of MgO in LF slag is either below or above 8%, steel ladle life degrades.

CONCLUSION

In SAIL-ISP the dominant factor for increase of steel ladle life of supplier 'A' by 31.59% in phase Y from phase X is the reduction in empty time of steel ladles which has simultaneously prompted a decrease in metal holding time, arcing time, increase in number of heats per ladle and also reduction in the no of bottom purging failures. It can be concluded that high empty time in steel ladle leads to cooling of the refractory lining which results in higher thermal shock during next tapping of liquid steel.

REFERENCES

[1] A. P. Luz, F. C. Leite, M. A. M. Brito, and V. C. Pandolfelli, 'Slag conditioning effects on MgO-C refractory corrosion performance', *Ceram Int*, vol. 39, no. 7, pp. 7507–7515, Sep. 2013, doi: 10.1016/j.ceramint.2013.03.001.

[2] I. O. Otunniyi, Z. v. Theko, B. L. E. Mokoena, and B. Maramba, 'Major determinant of service life in magnesia-graphite slagline refractory lining in secondary steelmaking ladle furnace', in *IOP Conference Series: Materials Science and Engineering*, Nov. 2019, vol. 655, no. 1. doi: 10.1088/1757-899X/655/1/012003.

[3] K. Beskow, N. N. Tripathi, M. Nzotta, A. Sandberg, and D. Sichen, 'Impact of slag-refractory lining reactions on the formation of inclusions in steel', *Ironmaking and Steelmaking*, vol. 31, no. 6, pp. 514–518, Dec. 2004, doi: 10.1179/030192304225019360.

[4] G. Li *et al.*, 'Influence of working lining parameters on temperature and stress field of ladle', *Applied Mathematics and Information Sciences*, vol. 7, no. 2, pp. 439–448, 2013, doi: 10.12785/amis/070203.

[5] R. T. Cruz, W. v. Bielefeldt, and S. R. Bragança, 'Influence of ladle slag composition in the dissolution process of the dicalcium silicate (C2S) layer on doloma-C refractories', *Ceram Int*, vol. 43, no. 17, pp. 15360–15369, Dec. 2017, doi: 10.1016/j.ceramint.2017.08.076.

[6] R. A. A. Borges and G. F. B. Lenz e Silva, 'A statistical and post-mortem study of wear and performance of MgO-C resin bonded refractories used on the slag line ladle of a basic oxygen steelmaking plant', *Eng Fail Anal*, vol. 78, pp. 161–168, Aug. 2017, doi: 10.1016/j.engfailanal.2017.03.020.

A case study - life enhancement of alumina spinel burnt bricks for slag dumping area of ladle metal zone

Avishek Mitra[a], Sanat Kumar Hazra
Dalmia Bharat Refractories Limited, Rajgangpur, India
mitra.avishek@dalmiaocl.com

Abstract

In the present scenario, mostly magnesia carbon bricks are being used in the metal zone of steel ladle. But, the problem of these conventional resin bonded refractories are higher thermal conductivity, higher thermal expansion, carbon pick up in steel and heat loss/skulling. To achieve higher life, minimize carbon pick up in steel and to make the lining cost competitive, burnt Alumina--magnesia spinel brick is one of the best alternative material to magnesia carbon brick.

In an integrated steel plant in India, Dalmia Bharat Refractories Limited was supplying Alumina Spinel bricks in ladle metal zone for sometimes. The quality supplied was performing in all areas but the main issue was high erosion in the slag dumping area. Bricks of this area of Metal Zone were eroded faster then the rest area bricks for which pocket repairing of Slag dumping area is almost a regular practice which is the main constraint to achieve higher life.

This case study speaks about the development of a new quality brick with special additive to counter faster corrosion resulting in higher life of bricks at slag dumping area of metal zone. The physico-chemical properties of the developed brick along with its improved corrosion and spalling resistance are also discussed.

Keywords - Ladle, Alumia-Spinel, Slag Dumping Area;

INTRODUCTION

In the ladle, a refractory lined vessel, non-metallic slag-forming additives and other additions are used to make a particular quality of steel, frequently in vacuum conditions. The process temperature in LRF and other secondary refining units, normally is in the range from 1590°C to 1720°C. The molten metal is stirred with argon, reheated with an electric arc from carbon electrodes in the steel ladle placed in a ladle-furnace stand. Exothermic chemical reactions are used to raise the temperature of the molten metal in some plants also. After the required composition of the steel is achieved, tapping is done to ladle into a continuous steel casting tundish or into ingot moulds.

At present, Magnesia Carbon bricks are being used in steel ladle for higher life. The advantage of MgO-C bricks is its non-wetting property and superior corrosion and erosion resistance to slag and metal. By application of MgO-C bricks, the ladle life increases but there are some disadvantages like carbon pick-up in steel, chances of metal chilling due to high thermal conductivity, higher thermal expansion etc. which has prompted to find out the alternative.

In recent times, burnt alumina-magnesia spinel bricks have been used in ladle with successful results. This is a high purity, high performance material containing no carbon, thus benefiting the steel manufacturer to produce ultra-low carbon steel with no carbon

A case study - life enhancement of alumina spinel burnt bricks for slag dumping area of ladle metal zone

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pick up from the refractory. Bricks manufactured with high purity corundum and preformed spinel has been used in high capacity ladle to give good performance. Corundum with high volume stability and low reactivity and spinel forms a discontinuous micro-structure giving better thermal flexibility and good corrosion resistance with metal and slag.

In Plant A, Alumina Spinel bricks were being supplied in ladle metal zone for sometimes. The quality supplied was performing in all the areas but the issue was high erosion in the slag dumping zone. This is the weakest part of metal zone being identified as a thrust area. Slag dumping area of ladle metal zone is the most susceptible towards abrasion. Remnant refractory thickness of the area always found minimum irrespective of plant practise. Bricks of this area of Metal Zone were eroded faster than the rest area bricks for which pocket repairing of Slag dumping area is almost a regular practice which is the main constraint to achieve higher life.

Fig 1: Slag Dumping area of ladle metal zone

In this paper, used Alumina Spinel brick of slag dumping area has been analysed and found that the main wear factor was the high erosion & corrosion. The LOT (Left Over Thickness) of the eroded brick was around 0-20 mm. On analysing the used bricks, it can be seen that the metal penetration in these bricks through pores has accelerated the wear phenomenon. The metal penetration was making the brick structure dense and thus crack formation and structural spalling was occurring. So, if the physical and hot properties of the brick can be improved along with changing the morphology to arrest this crack propagation, then this erosion and corrosion be controlled.

EXPERIMENTAL

Commercially available various grades of fused alumina grains with different size fractions and fused spinel were used as major raw materials. Three different batches of alumina spinel bricks were manufactured, all in the same base material but 3 different additives, A, B & C were added.

The set of trial samples were shaped into bricks by using industrial hydraulic press with a specific pressure of 1.8 Ton/cm2 and samples were dried at 110°C for 24 hrs and then at 160°C for another 24 hrs. After drying, the samples were fired at 1700°C with predetermined heating schedule and soaking time in high temperature tunnel kiln. The fired samples undergo testing as per the industrial testing practices. Apparent porosity (AP), bulk density (BD), cold crushing strength (CCS), and hot modulus of rupture (HMOR) was determined by the conventional three-point bending test conforming to ASTM C133-97 at 1400°C, using HMOR testing apparatus (Netzsch 422, Germany). Micro structure analysis were done by using Optical Microscopy (Leitz orthoplan pol optical microscopy with image analyzer). Each value of the tested samples was average of three parallel samples. Pore size analysis was also done along with rotary drum test with slag and metal at 1650°C to 1700°C for 10 hours

RESULTS AND DISCUSSION

Table I shows the physical properties of different batches of Alumina Spinel bricks. T-1 and T-2 showed low porosity but the HMOR of T-2 is much higher than that of T-1. T-2 shows lowest porosity and highest HMOR in comparison with the other three batches. Optimum quantities of different size fractions are selected based on the Andreasen's equation to achieve highest packing density and subsequently low porosity. As, impurity is very low and matrix is dense due to proper selection of coarse to fine ratio, the bricks shows high HMOR. Addition of ultra fine additive B, increases the bulk density because additive B is denser than spinel and Fused Alumina.

Table I: Physical properties of different Trial batches

Sample	RS	T-1	T-2	T-3
AP (%)	17.6	16.8	15.4	18.3
BD (gm/cc)	3.11	3.16	3.25	3.09
CCS (kg/cm²)	730	1077	1089	1074
HMOR (kg/cm²)	61	83	127	53

Erosion during slag dumping is even more severe in this zone due to abrasion and chemical reaction will CaO. Higher HMOR implies higher resistance of the refractory to this type of erosion. The HMOR of T-2 is 127 kg/cm2 at 1400°C, which is almost double of that of the HMOR value of Regular Alumina Spinel brick, RS (61 kg/cm2). The high strength indicates good bonding due to high firing temperature and a low-impurity matrix.

Fig 2 shows that the pore size distribution analysis of samples RS, T-1, T-2 and T-3. Addition of special ultra fine additive in T-2 closes the interstitial pores which is very clear from the PSD of T-2. The percentage of finer pores are greater in number in T-2 than others. Moreover, higher firing temperature also indicates the same from RS sample. In T-2, the maximum amount of pores are between 5-10 micron, whereas in other samples, the maximum concentration is between 10-20 micron.

Pore size distribution is an important factor when evaluating the corrosion resistance. The fewer pores and the smaller in size create dense matrix structure and able to keep the grains embedded.

Fig 3 shows the micro-structural analysis of T-1, T-2 and T-3. The matrix part of RS has loose texture due to presence of high porosity surrounded by corundum grains. Fig 3C shows the micro-structural analysis of T-2. The matrix is denser with less number of channel and open pores due to better sintering between grains. In Fig 3C, the extent of bonding in T-3 is lesser than that of T-2, with several number of pores. The same is also seen from Table 1. T-2 has a dense microstructure where coarse corundum and spinel particles are embedded in a homogeneous matrix of a mixer of fine particles of corundum.

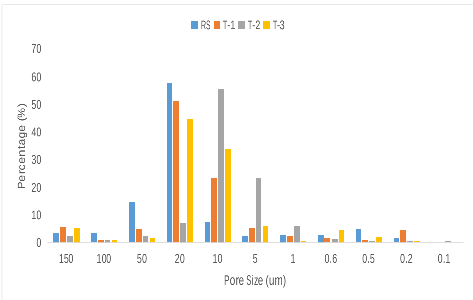

Fig 2: Pore size Analysis of the Trial samples

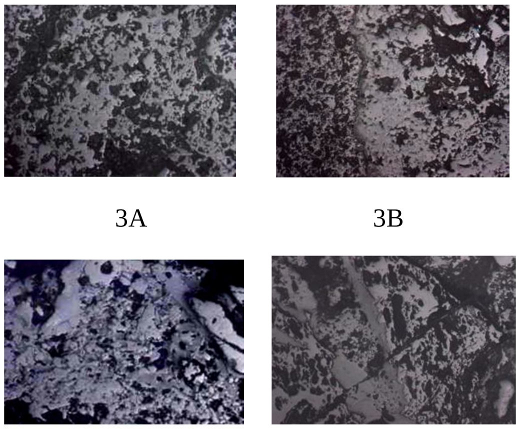
3A 3B

Fig 3: Photo micro-graphs of different batch compositions

Fig 4 shows the slag corrosion results of RS, T-1, T-2 and T-3. It is clear that the corrosion index of T-2 is almost half of that RS.

High surface area due to direct bonding and less amount of pores, provides better distribution and spinel formation along with large crystal size of corundum grains - improves corrosion resistance. Formation of large number of sub-micron pores (<0.2µm) by high temperature firing and addition of special ultra fine additive reduces the penetration of metal/slag due to large contact angle between refractory and metal/slag.

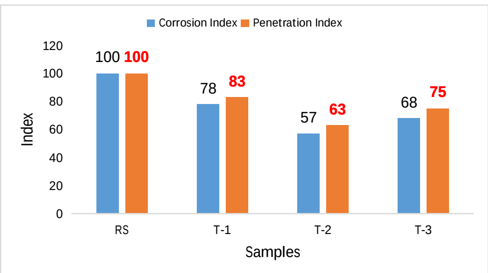

Fig 4: Corrosion & penetration Test Data of samples

FIELD TRIAL

In Plant A where the RS bricks were being used in slag dumping was giving life around 50-55 hts and a LOT (Left Over Thickness) of the eroded brick was around 0-20 mm.

1 set of developed Alumina Spinel bricks of formulation T-2 was sent to Plant A and average life achieved 198 with 3 repairs.

During 1st repair at 55 heats, the erosion of Slag Dumping (SD) zone have been found to be improved. Previously during 1st repair, normally 01/02 layer of Metal Zone (MZ) bricks were to remove to get the desired width for relining of Slag Zone (SZ) bricks, but in this case only 09 layer of SZ repaired, without any removal of MZ layers.

During 2nd repair at 94 heats, erosion found in 3-4 bricks in SD area. The LOT of SD area bricks varied from 40-70 mm.

During 3rd repair at 137 heats, only 5-6 bricks of SD zone was found eroded where as previously while using RS, total 12 bricks were being eroded. The LOT of SD area bricks varied from 40 - 60 mm.

After the ladle was put down after 198 heats, the LOT in metal zone was 70-80mm while that of SD area is around 30-50 mm

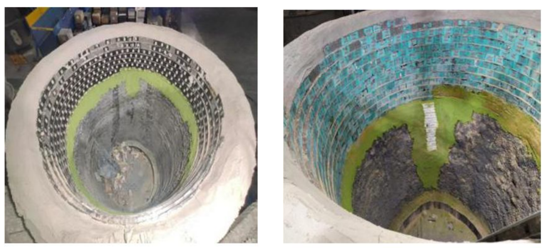

Fig 5: Ladle during repairs

CONCLUSION

Physio-chemical, thermo-mechanical and microstructure studies were conducted to investigate the effect of different additives on Alumina-Spinel brick. The current study shows that it was possible to improve the properties by addition of 2% special ultra fine additive B and firing the Alumina Spinel brick at higher temperature. With addition of additive B, the HMOR increases by around 100% which is a very important property giving better corrosion resistance. The special additive also reduces the internal pore size of the brick. Moreover, at higher temperature, the sintering between grains are better which leads to less number of pores. It could be shown that addition of additive B along with high temperature firing not only improved the densification of the brick matrix but also lead to higher corrosion resistance against metal and slag. Same has also been proved at Plant A, where the life of slag dumping area has increased significantly with bricks with recipe T-2.

ACKNOWLEDGEMENT

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REFERENCES

[1]John Harvey and Samantha Birch, “Important factors in the selection of steel ladle lining material”; Tehran International Conference on Refractories, 4-6 May 2004.

[2]Mori & al., “Structure change of alumina castable by addition of magnesia or spinel”; Taikabatsu Overseas; vol. 15; n03; 1995; pp. 20-23.

[3]J.T. bailey and R. Russel, “Magnesia rich MgAl2O4 spinel”; Am. Cer. Soc. Bull, 50(5) 493-496 (1971).

[4]K.H Sandhage and G J Yurek, Journal of American Ceramic Society, 73[12], 1990, pp 3633-3642.

[5]S. Riaz, K.C. Mills and K. Bain, Ironmaking and Steelmaking, 29, 2002, pp 107-113

[6]D.D.Poddar and S. Mukhopadhay, “Spinel-Bonded Basic Castables in Relation to Spinel formation agent”; Interceram, 51[4], 282-288 (2002)

[7]Y.C. Ko, Interceram 51[6], 2002, pp 388-392

[8]Riguad & all., “Volume stability of spinel bonded magnesia Castables”; Key Engineering Materials; vol. 132-136; 1997; pp. 1818-1820.

[9]S.K.Chen, M.Y.Cheng, S.J.Lin and Y.C.Ko, “Thermal characteristics of Al2O3-MgO and Al2O3-spinel Castables for steel ladles”; Ceramic International, 28, 811-817, (2002).

[10] W.E.Lee and S.Zhang, VII International Conference on Molten Slag Fluxes and Salts, The South African Institute of Mining and Metallurgy, 2004, pp. 309-319.

[11] Bannenberg, “Demands on refractory material for clean steel production”; UNITCER 1995; vol 1; pp 19-22

[12] S. Bharti, R. Kishore, S. Biswas and A.R.Pal, Proceedings of IREFCON 2014, pp 135-140

[13] Aksel, P.D. Warren, F.L.Riley; “Fracture behaviour of Magnesia and Magnesia-spinel Composites before and after thermal shock”; J.Eur.Cer.Soc.,24,2407-2416 (2004)

Performance improvement of Steel ladle life by modelling operating parameters

Nabid Anjum Khan*, Goutam Ghosh, Sudhanshu Kumar, Sanjoy Biswas, Devendra Prasad Singh, Santanu Saha, Prasanta Panigrahi, Sujat Ali Khan
Tata Steel Kalinganagar
Author's email: nabid.khan@tatasteel.com

ABSTRACT

Operating parameters have enormous influence on the performance of the steel ladle refractory. Critical operating parameters had been used for the model building for steel ladle refractory life in Tata Steel Kalinganagar SMS shop. Optimising the operating parameters through the digital model building will help to enhance the performance of the steel ladle. We have conducted technical understanding of 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 was built with the help of various analytics tools with the inhouse analytics team. We would be able to predict the steel ladle life with the operating parameters.

The objective with the study finally leads to the performance improvement of the steel ladle life by 5 to 10 heats. The financial benefits along with the insight's generation will be the outcome of the model. The further study will be conducted to deploy the model in other shops of the Tata Steel.

Keywords - Steel ladle: Slag Zone Life; Operational Parameters; Predictive model; Remaining Useful Life (RUL).

INTRODUCTION

Modern steel ladle is used not only to merely transport liquid steel from BOF to caster, but also to act as a reactor vessel where refining of steel takes place to reduce impurities, carbon, alloy addition and killing (Al &/ Si) of steel to reduce oxygen and other gases.

Many factors could affect the performance of a steel ladle, for instance, lining configurations, slag compositions, operation processes and operational parameters [1]. An optimal lining configuration under defined service conditions is crucial for steel ladle campaign life. At TATA Steel Kalinganagar, Steel Ladles are lined with Spinel bricks in metal zone, Mag-C bricks in Slag Zone and AMC bricks in bottom, which provides a metal zone life of ~ 150 heats with 2 slag zone and bottom repairs. Slag zone life varies in a wide range from 40-65 heats with same quality of bricks irrespective of suppliers. To understand the role of various parameters and their effects on ladle life were considered in this project.

Total 10490 heats details, slag chemistry during that period and 223 slag zone campaign detail parameters were observed. Also, over 668 parameters like steel grades, different secondary processes (LF, CASOH, RH), tapping temperature, ferro alloy additions, addition of different fluxes, treatment duration, arcing, metal holding duration, ladle ideal durations, quality of refractories etc. were taken into the consideration for model preparation.

Literature survey shows, with the development of computer techniques and algorithms, many advanced techniques, e.g. the finite element method, Taguchi method and BIG data management etc easily utilized or integrated to facilitate the refractory lining design [2-4].

In the present paper, we developed the model which could predict the remaining life of the ladle based on the operational details of that campaign. In addition, the significant operating parameters and their contributions to the remaining ladle life are predicted to take necessary actions for improvement of the ladle life of the same campaign.

MODEL DEVELOPMENT

The whole process can be divided into different stages. In first stage, heat details, slag chemistry, ladle circulation & ladle life details during that period were collected. Then cleaning of data by correction of data/junk data were carried out. After that formatting of model data were done for data processing. Petiotization of data, identification of exceptions and based on the history data the current remaining useful life data prediction were formulated.

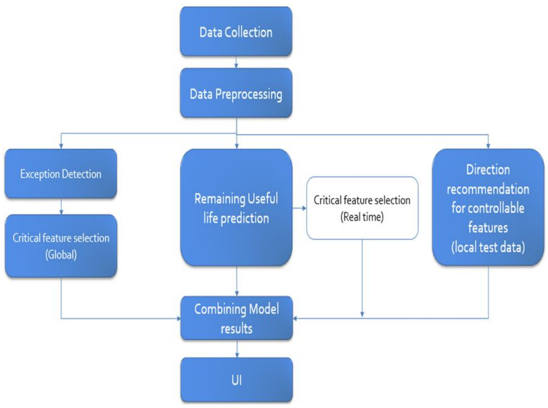


Fig- 1: Framework for Remaining useful life prediction

After prediction of residual useful life, the sample run of data for 48 slag zone campaign were carried out with real time data & corrections were done & finally a model performance ratio of ~ 93% correctness were achieved.

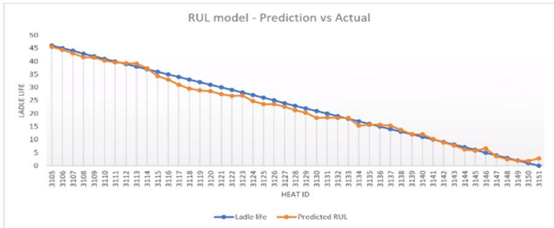


Fig-2a. RUL prediction with actual life.

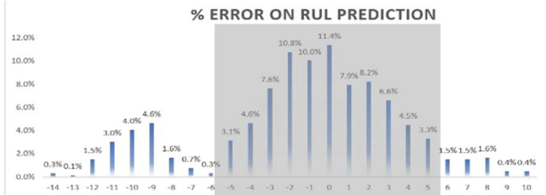


Fig-2b. RUL prediction - Error on prediction

The model was also able to show the critical features in real time basis (shown in fig 3 &4).

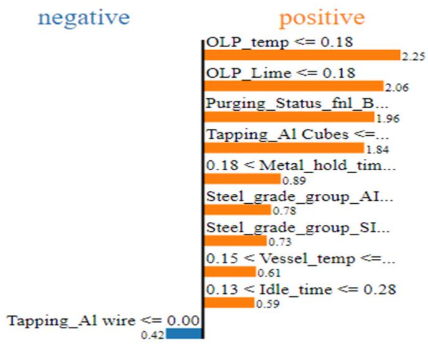


Fig- 3: Critical Feature's impact (on good prediction)

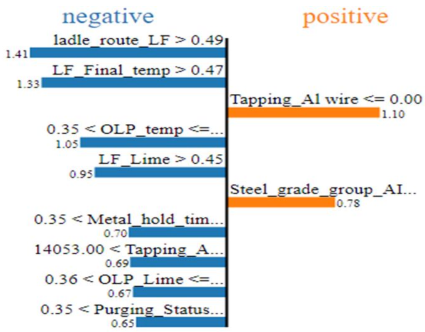


Fig-4: Critical Feature's impact (on bad prediction)

After construction of the model the output is designed, architectural diagram (shown in Fig 6) for online collection of data from different servers to model server and collaboration of the data to input/output table through UI *workstation were carried out with the help of TATA Steel Analytical & IT team.*

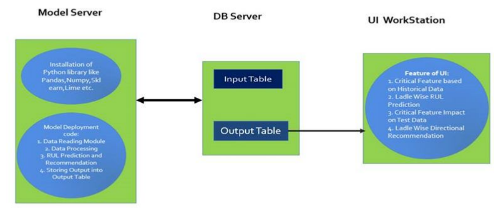


Fig-6: Arcitecture Diagram

RESULTS & DISCUSSIONS

Ladle prediction model output (Fig-7) giv details of RUL, the negative parameters (r color) & positive parameters (green colc also trend of all parameters.

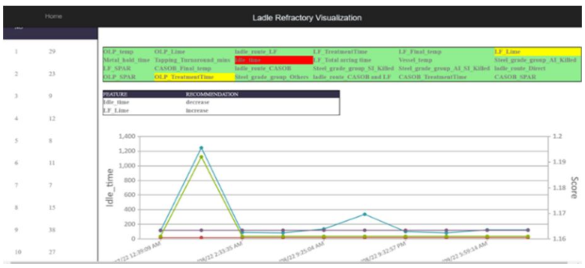
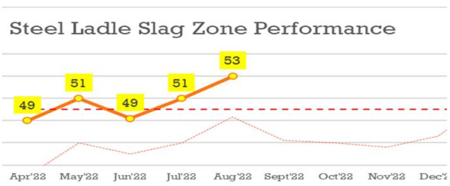


Fig-7: Model output

Steel Ladle Slag zone average life enhanced from 48 to 53 heats as a result total ladle life was increased by 5-6 heats. Implementation of model was started around 3 month back & we are expecting further increase in ladle life by controlling the operating practices.



The accuracy of the model is based on similar process conditions taken as testing parameters. The change in process or introduction or change in the process may affect the performance on the model. The model efficiency increases with the increase in ladle life, model accuracy is within an accuracy range 90 ± 5 % with a ladle life > 25 heats.

CONCLUSION

Here we conclude the contributions of this paper as followings:

- *We develop a more accurate predictive model for remaining steel ladle life prediction, which is significant in practical applications.*
- *Using the model, we can analyze the parameters effecting the lower life, which improvise to control the parameters to avoid deterioration of remaining life.*
- *Visual representation of parameters & alarming triggering /pop-up of the same to the operator.*
- *Enhanced ladle management i.e., Installation, ladle preheating & preparation for circulation.*
- *Targeted Ladle life improvement by 8-10 heats.*

ACKNOWLEDGEMENT

To formulate the prediction model from a complex system took a combined effort of the whole Operation, Refractory, RTG, IT & Analytical team makes it possible. We would like to thank everyone associated with this project indirectly.

We would like to thank TATA Steel Management & team of International conference of future Refractories in Iron & Steel Industries for providing opportunities to present our work.

REFERENCES

1] A. Ghosh. CRC Press. Secondary steelmaking: principles and applications, (2000).

[2] R.K. Roy. Society of Manufacturing Engineers. A Primer on the Taguchi Method: 2nd edition, (2010).

[3] A. Hou, S. Jin, H. Harmuth, D. Gruber, A method for steel ladle lining optimization applying thermomechanical modeling and Taguchi approaches. JOM, Vol. 70, pp. 2449–2456, (2018)

[4] S. Jin, D. Gruber, H. Harmuth, J. Soudier, P. Meunier,H. Lemaistre, Optimisation of monolithic lining concepts of channel induction furnace. International Journal of Cast Metals Research, Vol. 27, pp. 336-340, (2014).

[5] L.A. Dobrzański, J. Trzaska, A.D. Dobrzańska-Danikiewicz. Use of neural network and artificial intelligence tools for modeling, characterization, and forecasting in material engineering. Hashmi S, Batalha GF, Van Tyne CJ and Yilbas B (eds.). Comprehensive materials processing, Vol. 2, Elsevier; (2014), pp. 161-198.

[6] MathWorks. Deep learning toolbox: user's guide (R2018b)

Implementation of Double Porous Plug Gas Stirring in Steel Ladles to Improve Gas Stirring Efficiency and Increase Ladle Lining Life

Rajeev Kumar Singh[1,a], Kiran Kr. Keshari[2]
[1] *Research & Development Center for Iron & Steel, SAIL, Ranchi, Jharkhand-834002*
[2] *Research & Development Center for Iron & Steel, SAIL, Ranchi, Jharkhand-834002*
[a] Corresponding author's email: singhrajeev@sail.in

Abstract

Gas stirring through porous plugs located in the bottom of the ladle is an effective method employed in today's metallurgical industries to enhance melting of alloys and improving its homogenization in steel melt. It is also utilised for improving the slag metal interaction in the ladle furnace. The efficiency of alloy dissolution and slag metal interaction is intricately related to the melting and mixing phenomena in steel ladles. The present study focuses on mathematical and physical modeling of gas stirring of liquid melt for mixing of slag and metal in a steel ladle. The effect of stirring the vessel using single porous plug was compared against a double porous plug system. Based on the results of the mathematical and physical modeling studies, steel ladles at Durgapur Steel Plant, SAIL were converted from single plug system to double porous plug system. The objective for the implementation was to reduce ladle lining erosion and improve lining life. As a demonstration trial one ladle was converted from single to double porous plug arrangement. Mixing characteristics of the slag and metal, thermal homogenization of the steel melt and refractory lining erosion pattern were used as parameters to evaluate the process efficiency. Results from the plant trial showed better homogenization of the steel melt and increase in lining life from 45 to 55 heats. Encouraged with the results, plant gradually converted all steel ladles from single porous plug to double porous plug. At present the average ladle life in the shop is around heats, wherein a major contribution to improvement has come from implementation of the double porous plug gas stirring.

Keywords – Gas Stirring, Steel Ladles, Double Porous Plug, Secondary Refining

INTRODUCTION

To accurately meet the composition of liquid steel, ladle furnace steelmaking requires improved efficiency of secondary refining operations such as ferro-alloy dissolution and mixing of the steel-slag bath. The slag metal reaction, deoxidation reactions between the molten alloy and bulk liquid, formation of inclusions and its floatation to the slag for removal, are important process steps which are intricately related to ferro-alloys dissolution, fluid flow and intermixing in the steel ladle. Gas stirring is a common ladle stirring mechanism in which gas is injected through porous plugs located in the bottom of steel ladle [1].

Typically, single or double porous plugs are present in the bottom of ladle for injecting argon as the gaseous medium. Double porous plug helps in improving mixing characteristics of the ladle and improve ladle lining life [2]. Implementation of a double porous plug system also leads to a number of other benefits like improved chemical and thermal homogenization, lesser slag mouth jamming, uniform refractory, and lesser return heats.

The present work involves physical and mathematical modeling of gas stirring in 120T ladles of Durgapur Steel Plant, SAIL, and implementation of the double porous plug system in the ladles.

APPROACH

First a feasibility study was carried out based on the existing process parameters. For this, fluid flow during gas stirring was simulated using existing gas flow rates for the existing configuration of single porous plug. Next, two different configurations of double porous plug were mathematically simulated for comparison with the existing flow conditions. Based on ease of operation in terms of maintenance in plant, one of the double porous plug configurations was considered for implementation in actual ladle. This configuration was also validated using a physical model for analyzing slag-metal intermixing. One ladle in plant was converted to double porous plug arrangement for plant trials. Gas stirring through double porous plug was then monitored in this ladle for evaluating the thermal homogenization, porous plug opening, reduction in treatment time and refractory lining erosion.

EXPERIMENTAL

A. Mathematical Model

Mathematical simulation of fluid flow was performed for a 1/5th scaled down model of a 120 T gas stirred ladle. This was used to analyze fluid flow and mixing time in gas stirred ladles for different porous plug arrangement, viz. single porous plug and double porous plug configuration as shown in Figure 1.

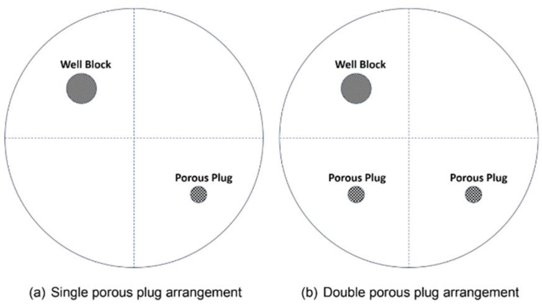


Figure 1: Arrangement of porous plugs in ladle bottom

For simulation of fluid flow, liquid-phase continuity and momentum conservation equations together with turbulence models and system of associated boundary conditions represent the common core of the mathematical model. The effect of rising gas bubbles on the fluid flow was coupled using a Discrete Phase Model (DPM) as it offers a simple calculation procedure and ease of use. This method does not require prior specification of gas fraction and plume dimensions. It only requires drag coefficient and bubble diameters which are readily available in literature.

The mathematical model assumes isothermal, turbulent, steady three-dimensional flow conditions. The upper buoyant slag phase is ignored, and the bulk liquid-air interface is assumed to be flat and mobile. Only gas phase can escape rom the top surface. Discrete mono-sized bubbles are assumed to form at the plug surface and the bubble sizes are considered to remain constant during its rise through the liquid. Bubble-bubble interactions are ignored.

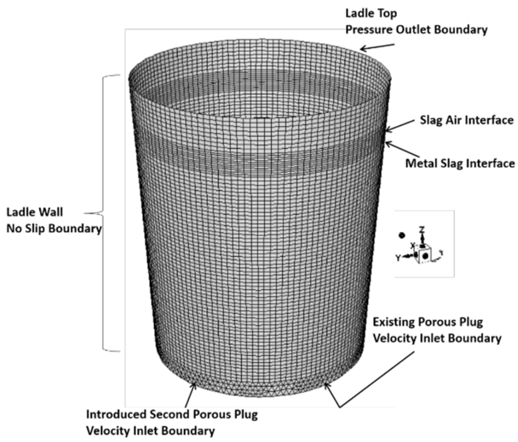


Figure 2: Grid distribution and boundary conditions

To model turbulence within the flow system as well as to track the discrete phase in a stochastic manner, the standard coefficient k-ε turbulence model was incorporated in the calculation scheme. Dispersion of bubbles due to turbulence in the fluid phase was predicted using the Discrete Random Walk (DRM) stochastic tracking model. To calculate mixing time, a tracer dispersion model was described using turbulent convective mass transport equation [3].

The computation domain was discretized, and appropriate boundary conditions of wall and free surface applied to the domain. The mathematical model was then solved using Ansys Fluent ® CFD software. The computational mesh and appropriate boundary conditions are shown in Figure 2.

The discrete phase model in conjunction with flow and turbulence model is solved in steady state. The volume averaged velocity was computationally monitored to know the instant when the flow had reached practically a steady state. Once the steady state flow is computed, species transport model is used for determination of mixing time. For this, a pulse addition of tracer is made in the top central region of ladle and concentration of tracer is monitored at the probe location and recorded in a text file. The species transport model equations are solved till a homogeneous concentration is recorded at the monitoring point. To speed up the calculation procedure, the species transport equation is solved alone, *i.e.*, there is no need to solve the flow and turbulence equations for mixing time calculation. From the concentration versus time data as available in text file, concentration vs. time plots is drawn in MS-Excel® and 95% mixing time is estimated.

B. Physical Model

For validation of the mathematical model, physical modelling of gas stirring in scaled down model was performed. The experimental setup is as shown in Figure 3.

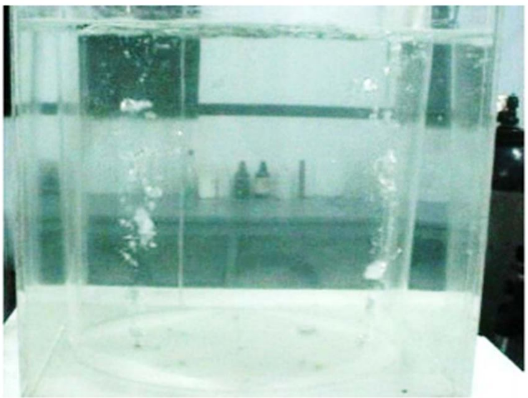


Figure 3: Perspex scaled down model of ladle showing plumes from two plugs

The experimental setup employed is a cylindrical Perspex vessel containing water at room temperature and having scale factor of 0.2 with respect to a full-scale ladle of 120 ton. In this vessel, nozzles were fitted at the bottom at various locations to facilitate gas injection into the water bath for different porous plug configuration. The cylindrical vessel is then placed inside a square Perspex tank to avoid diffraction of light from the round surface. The square tank also helps in maintaining hydrostatic pressure on both the surfaces of the ladle thus preventing it from deformation. Gas flow meters were fitted into the gas pipeline to measure and control the flow of gas. The gas pipelines are fitted into the nozzles that correspond to the required configuration to be studied. Rest of the nozzles are plugged. The ladle is first filled up to the scaled height with distilled water and then gas at scaled down flow rate is passed through the nozzle for stirring the bath. Once the bath has been stirred sufficiently it attains steady state and ready for mixing studies.

Mixing studies in the ladle were done through qualitative observation of the flow profile in the ladle using small paper pieces as tracers in the vessel. These soaked paper pieces moved along the flow direction in the vessel. Of interest were the paper pieces that were moving along the bottom as they evidenced the flow profile in the ladle close to the bottom. Further slag metal intermixing was studied by using a layer of mustard oil on top of water. While the mustard oil represented slag, water represented steel. The extent of mixing of the mustard oil in water qualitatively represented the extent of mixing in different configurations tested. The videos of the experiment were recorded for further analysis.

RESULTS

A. Mathematical Simulation of Flow Profile

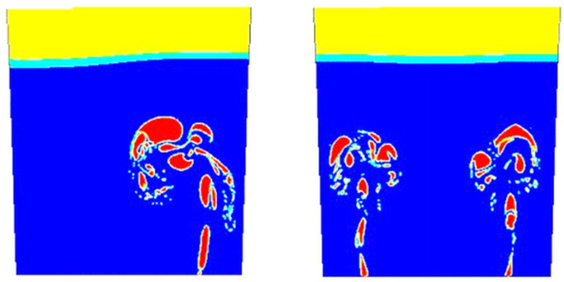


Figure 4: Initial flow profile: Single porous plug (Left), Double porous plug (Right)

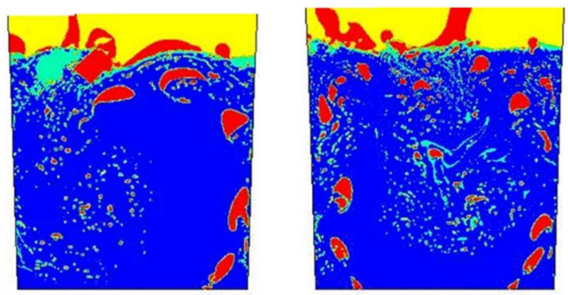


Figure 5: Mixing flow profile: Single porous plug (Left), Double porous plug (Right)

Figure 4 and Figure 5 show the initial and final flow profile in ladles fitted with single porous plug and double porous plug. It was observed that mixing homogeneity is better in case of double porous plug as compared to single porous plug ladle. Better slag metal interaction is observed in case of double porous plug compared to single porous plug. Mixing time for same total gas flow rate is lesser in case of double porous plug ladle as compared to single porous plug ladle. Comparison of mixing time results show that mixing time is lesser when the gas flow is distributed through two porous plugs rather than one as it leads to a more homogeneous flow field in the ladle.

B. Wall Refractory Erosion Profile

Shear stresses on the refractory lining generated due to fluid flow was evaluated for both porous plug configuration and is depicted in Figure 6.

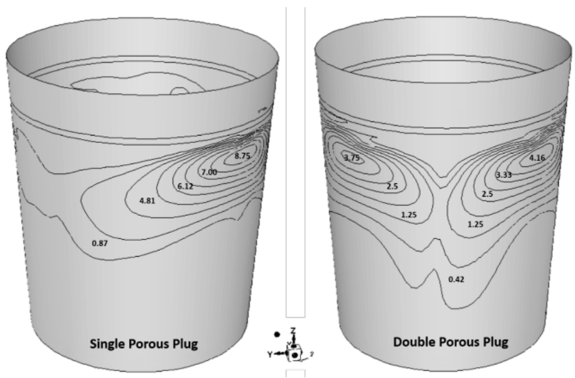


Figure 6: Wall shear stress profile on ladles with different porous plug configuration

The contour profile of wall shear stress helps to estimate relative extent of refractory wear as well as the region where more erosion is expected. It is evident from the results that wall stresses are reduce by approximately 50% by flow through two porous plugs. This will lead to lower lining erosion and thereby enhanced lining life.

C. Physical Simulation of Slag-Metal Intermixing

The fluid flow profile in the ladle and subsequent slag-metal intermixing was studied using mustard oil as slag and steel as water. The level of intermixing for different arrangements of porous plug is shown in Figure 7.

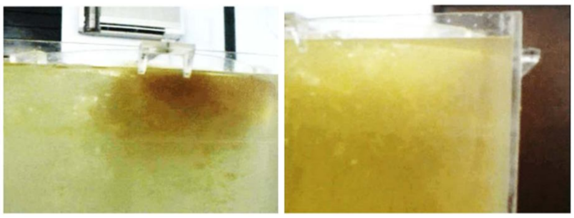


Figure 7: Slag-metal intermixing: Single Porous Plug (Left), Double Porous Plug (Right)

The flow profile suggests that better mixing can be attained for same flow rate using a double porous plug arrangement instead of a single porous plug. In single porous plug, all the slag is pushed towards the corner farthest from the porous plug. One big recirculating flow loop is established without much intermixing. However, when two porous plugs are used, the level of intermixing increases.

D. Plant Trials

Based on the results of physical and mathematical simulation, optimized location of second porous plug has been planned for trial in actual ladle. One steel ladle (#15) was modified accordingly with introduction of second porous plug. Bottom of modified ladle is shown in Figure 8.

Figure 8: Bottom view of modified ladle

Flux practice in double plug ladle was also modified from 100 kgs to 200 kgs calcined bauxite addition during tapping to maintain the fluidity of ladle top slag. Operation of trial ladle was monitored throughout the campaign. Opening of the porous plugs, flow from the porous plugs, coating of slag on ladle lining after completion of casting, porous plug and ladle life, slag dumping, bottom build up etc. was monitored during the campaign. After every cast, based on refractory lining condition, decision regarding further usage of ladle was taken. Mid repair of ladle was done at ladle life of 29 heats (normally mid repair is taken after 23-24 heats) with slide gate assembly and seating block was changed. After a total life of 55 heats, due to internal leakage of steel in slide gate assembly, ladle was removed from operation. On basis of visual inspection of refractory lining after 55th heat and measurement of refractory after de-bricking of ladle it was estimated that, in case of smooth operation of slide gate assembly, the ladle could have been used for another 5 heats.

During plant trial slag sample for each trial heat was also taken and analysed to ascertain the effect of extra 100 kg calcined bauxite added as flux. Tundish temperatures during casting was taken at regular intervals to ascertain steel bath homogenization. Similar data was also collected parallelly during the trial period for single porous plug ladles for comparative analysis of process parameters.

Analysis of recorded tundish temperature variations reflects that higher thermal homogeneity was achieved in double porous plug ladle as compared to single porous plug ladle. The tundish temperature variation recorded for both single and double porous plug ladle are as represented in Table 1.

Table 1: Variation of tundish temperature

Range	Double Porous Plug	Single Porous Plug
< 5 °C	50 %	30 %
5 to 10 °C	35 %	43 %
> 10 °C	15 %	27 %

Average analysis of slag samples from both the single and double porous plug ladle reflects a slight change in terms of alumina content of the slag due to extra addition of calcined bauxite during tapping as shown in Table 2.

Table 2: Variation in Slag Chemistry

Slag Component	Trial Ladle	Normal Ladle
% FeO	1.49	2.72
% CaO	50.18	47.07
% SiO_2	30.36	20.44
% Al_2O_3	5.13	3.14
% MnO	0.84	2.43
% MgO	9.11	12.32
% P_2O_5	0.06	0.13
% S	0.14	0.09
% TiO_2	1.18	0.99

The addition of higher amount of calcined bauxite leads to change in level of Al_2O_3. Due to this change in chemistry, we observe change in melting point and viscosity of ladle top slag which is shown in Table 3.

Table 3: Calculated melting range, viscosity and basicity of slag

Parameters	Trial Ladle Slag	Normal Ladle Slag
Melting Range	942 – 1585 °C	942 – 1842 °C
Viscosity at 1550 °C	1.436 Pas	1.661 Pas
Viscosity at 1575 °C	1.389 Pas	1.641 Pas
Viscosity at 1600 °C	1.342 Pas	1.622 Pas
Basicity	1.65	1.60

It can be from Table 3 that the melting point and basicity of ladle top slag is not much effected. However, we achieve a considerable improvement in viscosity of ladle top slag. This reduction in viscosity is responsible for fluid slag which enables slag coating on refractory walls during emptying of ladle while casting. This coating in turn helps in improvement of ladle lining life.

CONCLUSION

Based on the results of the trials, DSP has gradually converted all ladles to double porous plug and adopted the practice of regular addition of calcined bauxite during tapping. Gradually, slag basicity has been improved to an average of 1.6. Currently all ladles are having double porous plug arrangement for gas stirring through both the plugs. Adoption of double porous plug gas stirring along with modified flux practice has led to significant improvement in ladle lining life at DSP.

ACKNOWLEDGEMENT

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REFERENCES

[1] D. Mazumdar and R.I.L Guthrie, ISIJ Int., vol. 35, 1995, pp. 1-20
[2] F. Oeters, W. Pluschkell, E. Steinmetz, and H. Wilhelmi, Steel Research, vol. 59, 1988, pp. 192-201.
[3] Ansys® Fluent, 2019 Users Guide, Discrete Phase Model, ANSYS, Inc.

Interaction between Refractory and Liquid Steel Regarding Steel Cleanliness

Santosh Kumar[1,a], Biswasi Sunita Minz[2], Smita Toppo[1], Snehanshu Roy[1], Somnath Kumar[1] and Nityananda Mondal[1]
1R&D Centre for Iron and Steel, Steel Authority of India Limited
2Bokaro Steel Plant, , Steel Authority of India Limited
a Corresponding author email id: santosh@sail.in

Abstract

Chemistry and inclusion control are two of the main keys to the production of quality steel products. Adjustment of the high level of quality and of steel cleanliness is accomplished during secondary metallurgy and is maintained during continuous casting. Taking metallurgical aspects more and more into account imposes a new approach of interactions between metal, slag, atmosphere and refractory products. In a steel ladle or in a degassing device, many reactions between refractories, steel and slag can contribute to degrading the steel quality by direct dissolution of the refractory with or without precipitation, dissociation, volatilisation, reduction reactions between an oxide and a metallic element, combination of the refractory and a non-dissolved element present in the steel (inclusion). During continuous casting, the attachment of different oxides on the wall of submerged entry nozzle is still a hot topic for metallurgists, since it may cause clogging and influence castability and steel final quality.

Besides, the corrosion of the refractory could also result in the inclusions in steel. It has been confirmed that the MgO inclusions and calcium aluminate inclusions with MgO island(s) in Al-killed steel grades originate from the corrosion of refractory. Furthermore, alloys also contain some inclusions. These exogenous inclusions from refractory and alloys are an important source of non-deformable inclusions in Al / Si-Al/ Si–Mn-killed steel as well. So, the effect of refractory on the evolution mechanism of these exogenous inclusions also requires detailed investigation.

In the present paper, the effect of refractories on the exogenous inclusions in different mode of killed steel was reviewed.

Keyword: Refractory; Exogenous inclusion; Steel Cleanliness; Secondary refining; Continuous casting

INTRODUCTION

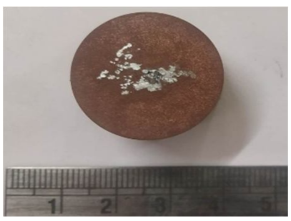
Molten steel is frequently contaminated to some extent by non-metallic particles that give rise to defects in the final products when the size of inclusion or inclusion concentration becomes significant. Continuous casting is considered the final stage of evolution in steel making and directly influences the quality of the end product. However, the effect of non-metallic inclusions on the quality of steel products is determined by its state in the final products after various thermal and mechanical treatments instead of that in the slab.

The demand for clean steel is increasing day by day in order to meet stringent quality requirements of the customers. Despite small content of non metallic inclusions in steel (0.01 – 0.02 %), they exert a significant effect on the steel properties. Therefore the control of steel cleanliness is one of the most important tasks for steelmaking. The interaction between refractory and liquid steel is one very important factor for the control of steel cleanliness. In industrial practice, the inclusions of MgO are found in liquid steel, and those inclusions come from erosion of refractory lining. Refractory lining erosion generally occurs at areas of turbulent flow, especially when combined with reoxidation, high pouring temperatures, and chemical reactions.

Exogenous inclusions from erosion/corrosion of refractory lining include well block sand, loose dirt, broken refractory brickwork and ceramic lining particle, is common source of large exogenous inclusions which are typically solid and related to the materials of the ladle and tundish themselves. They are generally large and irregular-shaped. These exogenous inclusions due to their large size, they may entrap deoxidation inclusions such as Al2O3 on their surface and act as sites for heterogeneous nucleation of alumina. The spherical exogenous inclusions are normally large (>50µm) and mostly multiphase. Small number compared with small inclusions; Sporadic distribution in the steel and not well-dispersed as small inclusions as they are usually entrapped during late formation during steelmaking, transfer, or erosion in the metallurgical vessels leaving insufficient time for them to rise before entering the casting in steel during teeming and solidification, lack of sufficient superheat, their incidence is accidental and sporadic. On the other hand, they easily float out, so only concentrate in regions of the steel section that solidify most rapidly or in zones from which their escape by flotation is in some way hampered. Consequently, they are often found near the surface. The occurrence of refractory erosion products or mechanically introduced inclusions are more deleterious to steel properties than small inclusions because of their large size.

Investigation of the SEN Clogging Material

As the steel cleanliness affect the castability by inclusion build up in SEN and ultimately clogging the SEN, so the analysis of the SEN deposit is also carried out. Some part of the SEN clogging samples was mounted for SEM-EDS investigation and some part were grinded for XRD and XRF analysis. The SEN clogging material and the mounted sample shown in Figure . In the SEN clog material it was appeared that there was some amount of entrapped of steel in the deposit.



The SEN clog material (indication of entrapped steel) and mounted sample of clog material

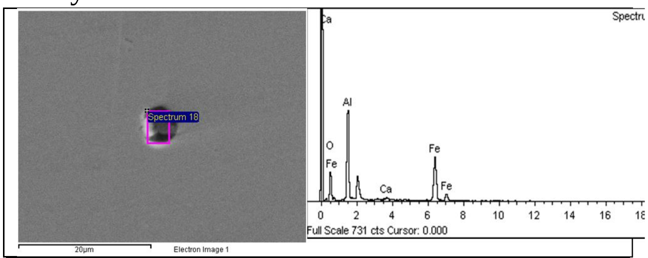
<u>Chemical Analysis of the clog material</u>

Sample	MgO%	Al_2O_3%	Fe_2O_3%
SEN Clog	5.06	47.23	37.94

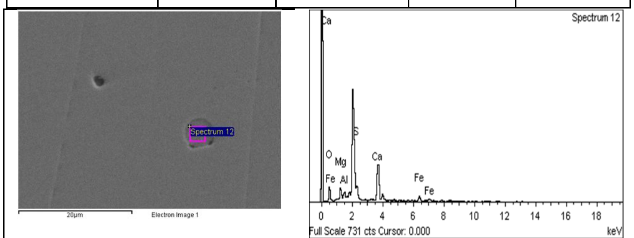
The chemical analysis showed that there was alumina and magnesium oxide as non metallic deposition with some entrapped steel.

Inclusion Characterization in SEM and EDS

To characterize the inclusion nature investigation have been carried out using SEM and EDS. After final preparation the samples were cleaned ultrasonically in acetone to remove out any foreign impurity that may enter during the processing. Then the samples were mounted and placed on the sample holder directly on the SEM Vacuum chamber for study.



Element	O	Al	Ca	Fe
Weight%	22.29	30.17	1.01	46.53

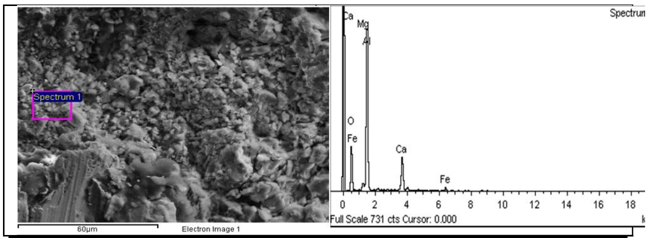


Element	O	Mg	Al	S	Ca	Fe
Weight%	44.41	7.25	3.16	7.13	28.04	10

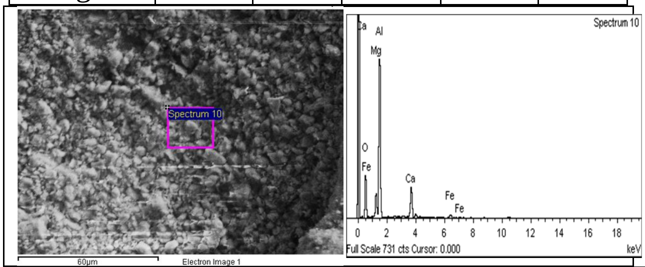
Secondary Electron Images of the inclusion with EDS Spectrum and semi-quantitative analysis

The SEM and EDS analysis showed that the inclusions are calcium-Aluminates oxide sometimes along with some MgO. The solid calcium Aluminates may form due to low Ca amount or not sufficient time for inclusion floatation after calcium treatment. However the globular shape indicates that the inclusions were in liquid form in steelmaking temperature.

SEM & EDS investigation of the clogged material in SEN



Element	O	Mg	Al	Ca	Fe
Weight%	46.88	1.59	36.92	12.15	2.46



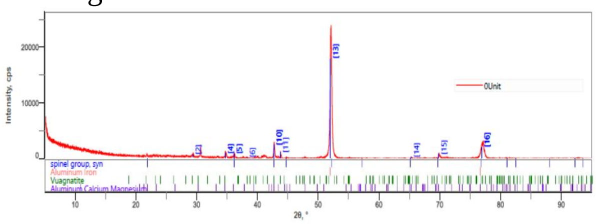
Element	O K	Mg K	Al K	Ca K	F
Weight%	42.91	5.67	36.97	11.1	3.30

Secondary Electron Images of the clog material with EDS Spectrum and semi-quantitative analysis of the clog material

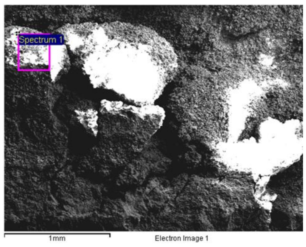
From SEM-EDS analysis it was found that the clog material is mainly aluminium-calcium oxide along with some magnesium oxide and steel entrapment.

Phase Analysis of Clog Material in XRD

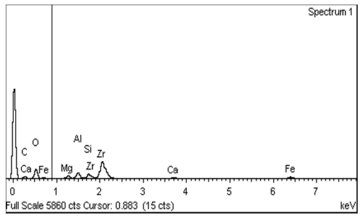
X –Ray-Diffraction analysis of the clog material has been carried out to determine the phases in the clog sample. The analysis showed present of Alumina-MgO spinel, Calcium-Aluminates, iron oxide is the main deposition in the clog material



XRD peaks of phases present in clogging material



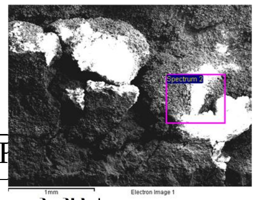
Secondary electron image indicating area for EDS analysis for spectrum 1



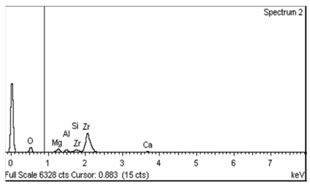
EDS spectrum of corresponding area

Semi quantities elemental analysis of the spectrum-1 is shown below.

Element	C	O	Mg	Al	Si	Ca	Fe	Zr
Weight%	1.02	44.28	2.57	4.96	2.67	1.64	5.88	36.98



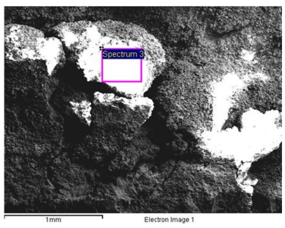
Secondary electron image indicating area for EDS analysis for spectrum 2



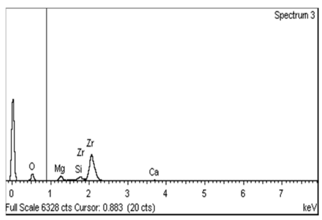
EDS spectrum of corresponding area

Semi quantities elemental analysis of the spectrum-2 is shown below.

Element	O	Mg	Al	Si	Ca	Zr	Totals
Weight%	38.1	4.3	2.49	1.7	1.04	52.38	100



Secondary electron image indicating area for EDS analysis for spectrum 3



EDS spectrum of corresponding area

Semi quantities elemental analysis of the spectrum-3 is shown below.

Element	C K	O K	Mg K	Si K	Ca K	Fe K	Zr L
Weight%	0.31	37.31	4.73	2.06	0.8	1.1	53.69

All the EDS analysis reveal the entrapment have very high amount of Zirconia along with some other oxides like alumina, silica etc. One potential source of high Zirconia may be the zirconia insert used in exchangeable metering nozzles.

Conclusion

The clogged material analysis showed the material are close in chemical nature with the inclusions in steel. High amount of calcium Aluminates in both inclusion and clogged material was found along with some Alumina-MgO spinel. Spinel may be generated with the interaction with refractory and steel alumina inclusions.

Refrences:

1. Inclusions in continuous casting of Steel, L. Zhang & BG Thomas: XXIV National Steelmaking Symposium, Morelia, Mich, Mexico, 26-28, Nov.2003, pp. 138-183
2. A review: influence of refractories on steel quality, Jacques Poirier, Metall. Res. Technol. 112, 410 (2015)

High performance alternate quality refractory for hearth of reheating furnace

I.Roy[1,a], M.K.Kujur[1], S.Aman[1], A.Paul[1], R.K.Pradhan[2], R.K.Singh[2]
[1]R & D Centre for Iron and Steel (RDCIS), SAIL
[2]SAIL Refractory Unit (SRU), SAIL
[a] Corresponding author's email: indranilroy@sail.in

ABSTRACT

Merchant mill of Durgapur Steel Plant (DSP) is producing TMT bars. It has one pusher type reheating furnace. For maintaining a steady production in merchant mill, DSP need to have consistence furnace hearth life of about 1 year. So, costly ZCC blocks are used in preheating zone.

Under prevailing operating conditions of RHF of Merchant mill, hearth refractory has to withstand very high abrasion, thermal shock and vibration during operation. The hearth refractory also should have high volume stability and high strength.

With this background, improved quality High Alumina brick has been developed jointly with SRU, IFICO and RDCIS to conduct trials in DSP. Trial bricks have been manufactured in SRU, IFICO and supplied to DSP after evaluation of its properties.

Developed brick was lined in preheating zone of reheating furnace of Merchant mill. These developed bricks give satisfactory result. As the bricks are manufactured in SRU, IFICO, also an in-house source for low cost hearth brick is now available with us.

Keywords: Reheating Furnace hearth; High abrasion resistance brick

INTRODUCTION

Merchant mill of Durgapur Steel Plant (DSP) of Steel Authority of India Limited (SAIL) is producing TMT bars. It has one pusher type reheating furnace. The maximum operating temperature of the furnace is 1330^0C and temperature of preheating zones is within 1000^0C.

For maintaining a smooth production flow, about one year lining life of furnace hearth is required. Furnace hearth has to withstand very high vibration, very high abrasion along with thermal shock during operation. Higher Erosion in preheating zone may leads to billet pile-up inside the furnace and forced to take unplanned shutdown. To avoid this problem, costly Zero Cement Castable (ZCC) blocks are used in preheating zone of reheating furnace of merchant mill, DSP.

In view of above, a study was jointly done with SRU, IFICO and RDCIS to develop suitable refractory for reheating furnace hearth which can be used at temperature around 1100^0C to reduce cost of refractory and maintain its life of 1 year.

EXPERIMENTAL

Raw Materials

Proper selection of raw materials plays very important role for manufacturing of high alumina bricks. Major raw materials used are given below:

White Fused alumina (WFA)

White Fused Alumina is highly pure synthetic alumina with high refractoriness, hardness, abrasion resistance and chemical inertness.

Specification of white fused alumina is given in Table – 1.

Table – 1: Specification of White fused alumina

Al_2O_3 (Min.), %	98
Fe_2O_3 (Max.), %	0.10
Na_2O (Max), %	0.50

Andalusite

Andalusite is an alumino-silicate material ($Al_2O_3.SiO_2$). Andalusite converts into Mullite ($3Al_2O_3.2SiO_2$) and vitreous silica on heating between 1350^{0}C and 1500^{0}C which helps to improve thermal shock resistance [1]. Specification of Andalusite is given in Table – 2.

Table – 2: Specification of Andalusite

Al_2O_3 (Min.), %	57
Fe_2O_3 (Max.), %	1

Calcined Alumina

Calcined alumina used for experimentation is a highly pure micro fine powder which was calcined at high temperature. Specification of Calcined alumina is given in Table – 3.

Table – 3: Specification of Calcined Alumina

Al_2O_3 (Min.), %	99
Fe_2O_3 (Max.), %	0.03
Na_2O (Max), %	0.50
SiO_2 (Max.), %	0.03

Fused Mullite

Fused Mullite is known for its high volume stability, high thermal shock resistance, high corrosion resistance, and high refractoriness. Specification of Fused Mullite is given in Table – 4.

Table – 4: Specification of Fused Mullite

Al_2O_3 (Min.), %	70
SiO_2 (Max.), %	29
Fe_2O_3 (Max.), %	1

Molasses was used as green binder during manufacturing of refractory bricks.

Development of improved quality brick

In order to develop preheating zone heart bricks with very high abrasion resistance, thermal shock resistance with high volume stability, detail laboratory evaluation was required. In laboratory, raw materials were taken in appropriate proportions (keeping total alumina percentage in the brick around 70%) and mixed in an intensive counter current mixer for around 5 mins. After that, 4-5% green binder was added and again mixed for another 15 mins. The green mix was then pressed at a specific pressure of 1 ton/cm^2. Generally, a higher pressing pressure reduced the apparent porosity and increased the cold crushing strength, the Young's modulus and the refractoriness under load [2]. Then after 24 hours air drying, the green bricks were dried in a dryer at 110^{0}C for 24 hrs. Then the samples were fired at 1500^{0}C.

Different properties like Apparent Porosity (AP), Bulk Density (BD), Cold Crushing Strength (CCS), Refractoriness Under Load (RUL), Repeat Permanent Linear Change After Reheating (Repeat PLCAR) and thermal shock resistance were evaluated with these samples.

AP was measured as per IS–1528, Part–VIII; BD was measured as per IS–1528, Part–XII; CCS was measured as per IS–1528, Part–IV; RUL was measured as per IS–1528, Part–II; thermal shock resistance was measured as per IS–1528, Part–III; Abradability Index (A.I.) was measured as per B.S. 1902: Section 4.6:

1985. Repeat PLCAR test was done by repeating the PLCAR test at 1500^0C for 3hrs.

RESULTS

Different properties of developed bricks are shown in Table 5 – 8. It is evident that results of AP, BD and CCS (Table – 5) of all the samples are comparable, but sample – 2 & 3 are the most impressive.

Table – 5: AP, BD and CCS of samples

Sample	Avg. AP (%)	Avg. BD (gm/cc)	Avg. CCS (kg/cm^2)
After Firing at 1500°C/ 3hrs.			
1	16.28	2.75	893
2	14.58	2.79	1026
3	15.88	2.77	1024

Other key properties like thermal shock resistance, R.U.L. (Table – 6) and Repeat P.L.C.A.R. (Table – 7) are also found within the acceptable range.

Table – 6: RUL & Thermal shock resistance of samples (Air quenching)

Sample	RUL (t_a ^{0}C)	Thermal Shock Resistance (Cycles, Air Quenching)
1	1600+	55+
2	1600+	55+
3	1600+	55+

Table – 7: Repeat PLCAR of Samples (at 1500^0C for 3 hrs)

Samples	PLCAR-1 (%)	PLCAR-2 (%)	PLCAR-3 (%)
1	0.166	0.229	0.073
2	0.027	0.317	0.067
3	0.088	0.133	0.026

Higher R.U.L. value shows higher strength of refractory at high temperature and lower Repeat P.L.C.A.R. value ensures volume stability during operation.

But, Abradability Index (A.I.) (Table – 8), where Lower A.I. value indicates higher abrasion resistance of refractory body, confirms that sample – 3 is the most suitable for the application.

Table – 8: A.I. of Samples

Samples	Avg. Abradability Index (AI)
1	72.97
2	48.12
3	43.21

Accordingly final quality specification was formulated for bulk production and plant trial. It is shown in Table – 9.

Table – 9: Final quality specification

Parameters	Value
Al_2O_3, %, Min.	70
Fe_2O_3, %, Max.	2
P.C.E., O.C., Min.	36
C.C.S., kg/cm^2, Min.	700
R.U.L., t_a, ^{0}C, Min.	1600
A.P., %, Max.	16
B.D., gm/cc, Min.	2.60
Repeat P.L.C.A.R., %, at 1500^0C/3 hrs.	1st P.L.C.A.R.: ± 0.50 2nd P.L.C.A.R.: ± 0.30 3rd P.L.C.A.R.: ± 0.10
Abradability Index, Max.	45
Thermal Shock Resistance, Cycles,	50

Min. By Air Quenching	

Cost of these developed bricks is also much lower as compared to the existing refractory being used for lining of preheating zone hearth of reheating furnace at merchant mill of DSP, SAIL.

PLANT TRIAL

Newly developed bricks were manufactured at SRU unit of SAIL for lining in the preheating zone of reheating furnace of Merchant mill, DSP, SAIL. Figure – 1 is showing the final condition of newly lined preheating zone hearth after completion of refractory lining with developed bricks.

Figure – 1: Final condition of preheating zone hearth after refractory lining

CONCLUSIONS

Following conclusions can be drawn from this present work:

- Developed high alumina brick (70% Al_2O_3) has high abrasion resistance, high volume stability, high refractoriness and thermal shock resistance.
- Developed bricks were installed in preheating zone hearth and performance is satisfactory.
- These developed bricks may reduce the cost of hearth refractory and can also be used in other areas of similar operating condition.

ACKNOWLEDGEMENT

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REFERENCES

[1] Roy Hagen, Cécile Lamy, Bjørn Myhre, Hong Peng.: Mullite formation, high-temperature properties of andalusite alumina based LCC and ULCC. Journal of the Ceramic Society of Japan. 112 (2004) [10] 517-532.

[2] Schafföner Stefan, Dietze Christin, Möhmel Steffen, Fruhstorfer Jens, Aneziris Christos G.: Refractories containing fused and sintered alumina aggregates: Investigations on processing, particle size distribution and particle morphology. Ceramics International. 43 (2017) [5] 4252-4262

Bottom Purging Improvement of Steel Ladle at LD#3 (TSL JSR)

Monoj Halder, Amit Banerjee*, Prasanta Panigrahi, Navneet Sinha, Brijender Singh*
Tata Steel Limited

Abstract

This paper describes the journey for improvement of porous plug performance at LD#3 TSCR. The main goal of Porous Plug is to create bubbles to float out all type of inclusion present in liquid steel as well as temperature & composition homogenization in secondary metallurgy .The cleanliness of steel is always a big issue in secondary refining & hence Porous plug plays the most important role there. Different type of Porous plug is available in the market like Random, Slot, Segment, Hybrid etc. Porous plug is selected for any steel industry depending upon the operation practice, chemistry of steel, ladle size & configuration etc. Reduction in bottom purging efficiency results in use of top lance purging, which ultimately results in improper homogenization of temperature and chemistry which causes downgrading of steel quality.

Present Bottom purging system was introduced in TSL JSR LD#3 from 2016 & there has been continuous study, analysis & different measures taken to improve the purging performance.

Porous Plug material complete characterization ,postmortem analysis, Trial of new design porous plug, Improvement in physical observation of purging through camera, improvement in safety Pad Inspection, Improvement in argon gas line connectivity, Auto coupler & mechanical leakages, Purging Plug maintenance improvement (Usage of PFD), Purging Programmer improvement, Ladle Logistic Improvement all these various studies & initiatives were taken to improve purging performance at LD#3. Currently the full bottom purging efficiency at LD#3 is 97%, further work is ongoing to achieve 99% full bottom purging efficiency.

Keywords – Steel Ladle, Bottom Purging, Porous plug, Tata Steel

INTRODUCTION

With the rapid development of steel industry, the focus is on making more & cleaner steel. Because of this bottom gas stirring is an important aspect in secondary steel making. This bottom gas purging is done with different type of porous plugs depends upon the operational practice, ladle size, final product chemistry. An inert gas is purged through the plugs. Advantage of bottom gas purging through porous plugs are (1) Removal of the inclusion by floating them out in the slag i.e. steel cleanliness (2) Uniform distribution of temperature throughout the bath (3) Homogenization of liquid steel (alloys & deoxidizing agents are added in presence of purging) .

Figure 1 shows a schematic diagram of a Ladle with purging arrangement (generally done at LF stations) .The LF(ladle Furnace) comes with top lance and one or more Porous Plug at ladle bottom .Bottom purging is most desirable method of gas purging & top lance is used in case of non-opening of Bottom purging . However, effective purging depends on the following ...

- Design & quality of Porous plug material
- Operational parameter & practice
- Maintenance of Purging system

Study was conducted to find out the cause of porous plug non opening at our LD#3 shop & increase the opening rate of plug.

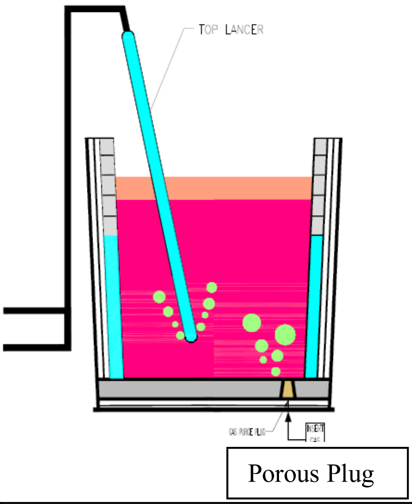


Fig 1: Schematic diagram of ladle with purging arrangements

1. *Mechanism of Ladle Bottom Purging*:
Most purging plugs are inserted at 2/3rd of the bottom radius from the middle of the ladle. In most of the cases steel manufacturer use one porous plug but in some cases two or more plugs are used which permit more rapid homogenization of the steel bath & reduce the ware of the plug .Different type of porous plug are available in the market like random porous plug , slot porous plug , segment porous plug , hybrid porous plug etc. . Porous plugs are either Alumina or MgO base & in some cases chrome oxide or spinel base.
With the different operational factors TSL LD#3 adopted segmented porous plug with very minimal slot gap. Considering the safety & performance there are different type of mechanism available in the market to support the porous plug – we installed SOC system.

2. *Analysis of Non-Purging cases at LD#3 & Initiatives taken over the years to Improve Purging Performance:*
Purging performance depends on various factors, non-effective bottom purging is reflected in the increasing use of top lance.

Fig 2: Schematic diagram of segmented porous plug

Data of Use of Top Lance was studied over the years, the Top Lance data from FY'16 to FY'21 (May'20) is given below in Fig 3.

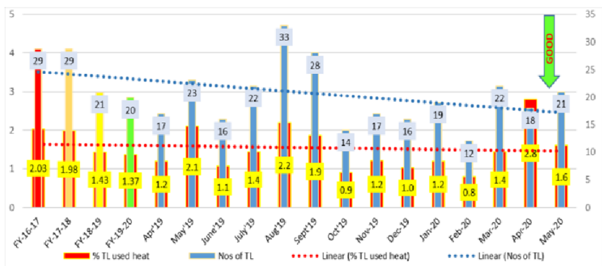


Fig 3: Top Lance consumption data at LD#3-TSL JSR

The data shows there has been an improvement over the years, in FY'17 Top Lance consumption was high as 29-30 pcs (yearly Average) but after that it reduced to 20 pcs (yearly Average) in FY'20. But, in 2019 there has been cyclic performance, in few months top lance consumption increased due to purging issues and again it dropped. All these shows, further improvement is required and even 18-20 pcs Top lance consumption per month is high, it needs to be reduced by improving purging efficiency.

Various causes/factors which can influence Bottom Purging & our improvement approaches are as follows…

2.1. *Physical inspection of plug opening*:
Physical observation of purging opening is one of the ways to see purging performance. Live camera was installed & access is given to LF control room for inspection eye opening of bottom purging.

2.2 *Argon Gas connection – Auto coupler & NRV valve related issue*
The proper placement of Ladle in the ladle transfer car & proper functioning of Auto Coupler plays a very vital role in bottom purging performance. Proper periodic maintenance/inspection of auto coupler system & finding of leakages is required before taking ladle in LF Operation. Many times, we found bottom purging issue due to leakage from auto coupler. O-rings of the auto coupler is changed as & when purging issues are faced in the ladle or it is damaged. The connecting pipelines are also areas of potential leakages. Sometimes infiltration of metal in between Poros plug segments is seen - One of the key reasons is back pressure, to minimize this NRV (Non return valve) is used. Improper functioning of NRV valve may lead to this issue. To suppress this issue regular check-up/maintenance of NRV valve is required. With this maintenance practice non opening of Porus plug is reduced drastically.

2.3 *Quality of Porous Plug:*

At LD#3, segment type purging plug is used. There are different components in this type of Porous plug but mainly it is divided into 4 parts (a) Fired Refractory segment: Fired Alumina Chrome Zirconia based material (b) Surrounding castable: Made of Alumina & Alumina magnesia base spinel based material (c) Indicator : made of high purity alumina with porous body (d) Metallic shell .

The life of porous plug is very much dependent on the quality of product like fusion of segment may choke the Plug, Higher erosion of plug may result low Purging plug life & higher gap between segments & castable may lead to metal penetration. To confirm this material quality, we check all the parameters of Porous plug in regular interval at our lab.

- Quality of segments & castable:

Fusion of segment may occur in presence of low melting phases. To counter measure this, we check the chemical analysis as well as PCE. Following table 1 is a representative analysis report of the segment part.

Table 1: Typical Chemical analysis of segment part

SEGMENT PART				
		$\%Al_2O_3$	$\% Cr_2O_3$	$\%ZrO_2$
New PP		90.10	4.50	4.78
Steel ladle No-13	Used PP-1	89.65	4.10	4.5
Steel ladle No-15	Used PP-2	89.74	4.01	4.27

PCE test was also conducted and values are more than 1800 Deg C.

Table 2: Typical Chemical analysis of castable part

SURROUNDING CASTABLE			
		%MgO	$\%Al_2O_3$
New PP		1.32	95.69
Steel ladle No-13	Used PP-1	1.21	94.95
Steel ladle No-15	Used PP-2	1.16	94.53

- *Remnant thickness of plug*

We have investigated the erosion pattern of few used plugs after certain lifetime & found safe remnant length in most of the cases as shown in Fig 4. Metal penetration was also measured at the same time.

Fig 4: Remnant plug thickness measurement (New vs Used)

- *Gaps in between Segments:*

Segment gap beyond specified norms may lead steel infiltration in between segment slits. Gaps may also occur due to various phase changes of refractory at higher temperature which may lead to shrinkage. 5-10 mm metal infiltration depth is common observed at various steel plant, however higher infiltration depth/thickness may be possible due to crack of surrounding castable or if the plug is blocked on the hot face (e.g. due to a solid bottom skull). Also, thermal shocks due to tapping into a ladle with a cold purge plug could lead to heavy cracks.

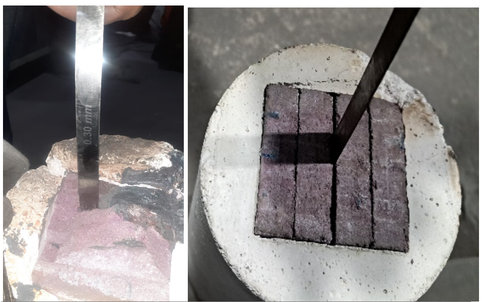


Fig 5: Gaps Between segments

2.4. *Other operational parameters*

Performance of bottom purging is also governed by the following operational parameters ….

- Ladle turnaround time should be as minimum as possible. Ladle should be hot during tapping. Purging should be started just before tapping.
- Tap temperature to be optimum
- Alloys & other charge material should not be charged on empty ladle – should be charged after ¼ of the ladle is filled with hot metal.
- For high holding time ladle purging to be maintained in open condition. If not, hard soft bubbling can be done.
- After the end of heat gas flow should not be stopped immediately.

2.5. *Porous Plug maintenance practice:*

After casting ladle is sent to the tilter for various maintenance activity like Plug cleaning. During plug cleaning oxygen lancing is done from front and at the same time nitrogen pressure is given from back to ensure no choking in segment during lancing. The back-line pressure should always be on the higher side than front side gas pressure during cleaning.

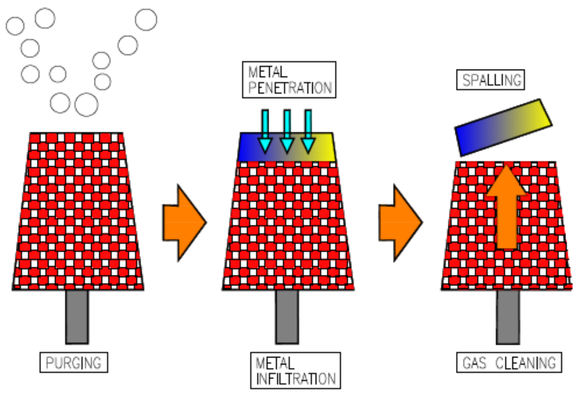


Fig 6: Gas Cleaning

To avoid the uncontrolled lancing PFD device was also installed in one of our tilters.

There are other factors also which are contributing the plug performance.

Conclusion:

As the metallurgical demands in secondary steelmaking increase so do the requirements for safe, efficient gas stirring plugs. As we have seen that efficient bottom purging is not only dependent on good quality & suitable type of porous plug but also plug maintenances practice, operational practice. Purging performance improvement is an ongoing journey at our LD#3 plant with all the cross functional teams to achieve the desired level of performance. Many new initiatives have been taken over the years and many more new trials & initiatives are continuing to reach the goal.

REFERENCES

[1] Efficient Ladle Purging for Hot Metal and Steel Teeming Ladle- A Viertauer, B. trummer, B.Spiess, G.Hackl, R.Ehrengruber, J. Bhattacharjee

[2] Innovative concepts for steel ladle porous plugs -Patrick Tassot,Calderys

[3] New Slit Plug for Ladle Refining - Eiji ISHIHARA＊１ Kimiaki SASAKI＊２ , Shinagawa Technical Report , Vol. 53 2010

[4] Holistic Approach for Gas stirring Technology in a Steel Teeming Ladle- Andreas Viertauer, Bernd Trummer, Leopold Kneis, Bernhard Spiess, Michael S.Pellegrino, Reinhard Ehrengruber and Gernot Hackl

Refractory Design Modification by Application of Monolithic Refractory Material and Improvement of Steel Ladle life in SMS-III BSP, SAIL

Amit Roy[a], Prasanta Saha
Bhilai Steel Plant, SAIL
[a] Corresponding author's email: amitroy1@sail.in

Abstract

In Bhilai Steel Plant (BSP), SAIL, SMS-III Steel Ladle Refractory Relining pattern was designed by the technology provider Primetals Technologies Limited (erstwhile Siemens VAI) along with RHI Magnesita (erstwhile RHI Refractories). After project stage the design was modified with monolithic refractories in back up lining along with change in lining pattern of working lining. The average steel ladle life of SMS-III increased with the modified design from 19.38 heats in FY 2018-19 to 38.78 heats in FY 2021-22. Along with increase of shop production the ladle life increased gradually, however, the in-house modified design has not only increased the ladle life, but also reduced the ladle side wall refractory failure. This paper is about the refractory design change by application of monolithic refractory material and improvement of BSP, SMS-III steel ladle refractory life through modification of refractory relining pattern.

Keywords – Steel Ladle; Refractory Design Modification; SMS-III; BSP-SAIL

INTRODUCTION

Steel Ladle in SMS-III are used to handle liquid steel from LD converter to continuous casting shop for casting, after treatment in secondary refining unit. The refractory relining pattern provided by the technology provider through project route was without back-up casting with the ladle shell. In the previous design relining pattern was first laying insulation bricks with the ladle shell, then high alumina bricks as permanent lining and magnesia carbon bricks as working lining. At the beginning of the shop frequent metal through observed in slag zone area. After mid repair of the slag zone eroded area along with shell welding work, the ladle used to take in the operation after preheating. The metal leakage from slag zone area was causing metal loss, sequence break up in continuous casting, ladle furnace area equipment damage, along with weakening the ladle shell. Refractory Engineering Department (RED), BSP, proposed modified design with monolithic refractory as back up casting to solve the issue. The design modification work was carried out maintaining ladle working volume and implemented successfully.

BRIEF DESCRIPTION OF BSP, SAIL

Bhilai Steel Plant (BSP), is one of the founding integrated steel plants owned by Steel Authority of India Limited (SAIL), India. The plant had been started in late fifties with six numbers of open hearth furnaces accompanied by ingot casting with an initial capacity of 1 MT per year, at Steel Melting Shop-1 (SMS-I). In 1967 the capacity of the shop increased to 2.5 MT per year with addition of certain facilities by increasing six open hearth furnaces capacity from 250 Ton to 500 Ton and addition of another four open hearth furnaces of 500 Ton capacity. During 1998 BSP had converted all the open hearth furnaces to total four numbers of twin hearth furnaces with 250 T + 250 T capacity each, with integrated production capacity of SMS-I shop 2.5 MT per year. The capacity of the plant was further expanded from 2.5 MT to 4.0 MT during mid-eighties by introducing three numbers of BOF LD Converter in SMS-II shop. With the view of modernization cum expansion 4.0 MT SMS-III shop was installed in the year 2018.

BRIEF DESCRIPTION OF SMS-III, BSP

BSP SMS-III shop was designed with capacity of 180/165 Ton. There are three numbers of BOF LD converters, three Ladle Furnace units, one RH degasser unit, two six strand billet casters, one six strand billet cum bloom caster and one three strand beam blank caster. The steel grades produced through steel ladles are Gr R-260E1, 1175HT, NCC Rails, SAIL TOWER, SWR10 etc.

INITIAL PHASE OF STEEL LADLE IN SMS-III, BSP

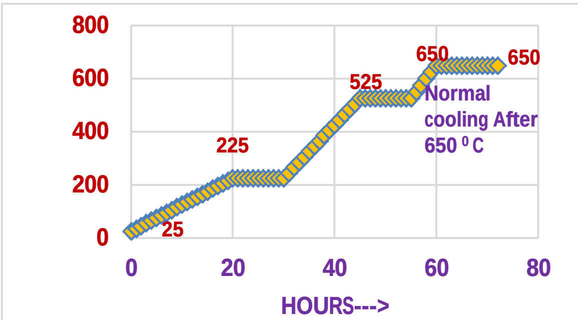
At the beginning, the relining work of SMS-III steel ladle was carried out as per project design without monolithic refractory casting with the shell as permanent lining. At the bottom relining pattern was two layers of each 32 mm insulation bricks, then 64 mm high alumina bricks followed by 250 mm magnesia carbon bricks and at bottom impact area 300 mm magnesia carbon bricks. At metal zone area back up lining was 10 mm ceramic fiber board, then 32 mm insulation bricks, followed by 76 mm high alumina bricks. Working lining was 152.4 mm magnesia carbon (Mgo-C) bricks. Back filling material of thickness 32 mm was used in between working lining and permanent lining. In slag zone area, back up lining pattern was same as metal zone, however, the working lining magnesia bricks thickness was of 203.2 mm. Among total 42 layers of side wall, metal zone consists of 32 layers and slag zone 10 layers including free beard area.

DESIGN MODIFICATION PHASE OF SMS-III STEEL LADLE

To avoid frequent slag zone refractory erosion, monolithic refractory lining with the inside shell planned by RED, BSP. First focus was given to the working lining thickness as the inspection procedure in the shop is visual. Hence, bottom working lining thickness kept as per project design. The permanent lining was designed as 10 mm ceramic paper at the bottom shell, followed by 65 mm monolithic casting and then 50 mm high alumina bricks. For anchoring before casting, long horn anchor of 50 mm height selected. Anchor fixing was done keeping horizontal and vertical length 200 mm and 150 mm respectively in staggered manner. After anchoring ceramic paper laying done but it had to be done with partially leaving the anchor welded area. After anchor welding and laying ceramic paper, casting of 65 mm was being carried out. Before bottom casting the well block and purging blocks area covered by round format so that monolithic refractory material application on that area could be debarred. Side wall casting format fitting work started after 24 hours of back up casting. The casting format was divided in three parts across the ladle height for better casting. After format fitting, step by step side wall casting done in three stages. The side wall casting thickness was of 65 mm throughout the ladle. For backup casting work, self-flow 90% alumina castable was used as monolithic refractory material. During each stage of casting, needle vibrator was used to ensure proper filling of format by monolithic castable.

After completion of backup casting by monolithic refractory, the ladle was kept in ambient temperature for natural drying. Then preheating done as per following preheating schedule prepared by the author.

PREHEATING SCHEDULE OF LADLE AFTER BACK-UP CASTING BY MONOLITHIC REFRACTORY



After preheating of back up casting the ladle was kept 24 hours for natural drying. After cooling of back up casting, ladle bottom was relined with 50 mm High Alumina (HA) bricks followed by 250 mm magnesia carbon bricks and in bottom impact area 300 mm magnesia carbon bricks. In between the gap of blocks (purging blocks and well block) and bottom working lining bricks, conventional high alumina castable used along with needle vibrator.

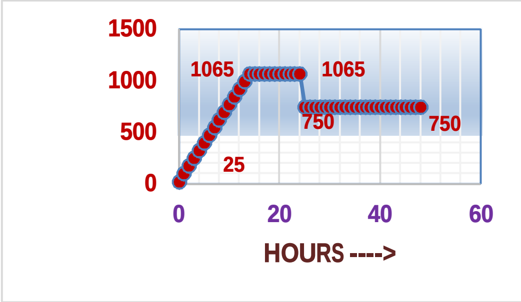
During relining of bottom safety layers by high alumina bricks, two layers of side wall safety lining of high alumina bricks lining were being done before starting of bottom working lining. In between the gap of bottom working lining of Mgo-C bricks and side wall safety lining conventional high alumina castable used along with needle vibrator. After this casting between bottom working lining and side wall safety lining, first layer of Mgo-C working lining bricks placed with 177.8 mm. The bottom working lining pattern was not as floating bottom. The bottom working layers were locked by side wall working lining and side wall working lining were being protected against falling during ladle dumping by top retainer plates at the top of the ladle shell along with conventional HA castable application at the top retainer plate area.

At metal zone, safety lining was being same as bottom safety lining of 50 mm high alumina bricks. Metal zone working lining thickness was designed with 177.8 mm instead of 152.4 mm in previous project design. As during mid-repair slag zone bricks used to be changed, hence, metal zone thickness increased compared to previous design to strengthen metal zone area refractory working lining. Throughout the 42 layers of side wall working lining and side wall safety lining, backfilling mass of 10 mm was provided for expansion joint in between two different quality of bricks high alumina and MgO-C.

The slag zone backup safety bricks were relined with magnesite bricks of 65 mm thickness followed by 203.2 mm MgO-C bricks. In top retainer plate area conventional high alumina castable used to protect the side wall bricks and to provide cushion for vertical expansion of overall side wall bricks.

After completion of total lining work mentioned above, ladle preheating schedule prepared by the author in view of overall ladle refractory lining pattern and to concise preheating time as much as possible for ensuring ladle availability in circuit as early as possible. In preheating schedule ladle preheating drier temperature kept 1065 degree centigrade maximum before taking the ladle for operation. The total preheating schedule is 24 hours. If there is a plan not to take the ladle into operation for next 24 hours then the temperature of preheating drier was kept below 750 degree centigrade.

Preheating Schedule After completion of relining work by shaped refractory bricks



Result After Design modification of SMS-III Steel Ladle

After the change of ladle back-up permanent lining from shaped refractory to unshaped monolithic refractory, the life of steel ladle increased from 19.38 heats in FY 2018-19 to 29.18 heats in FY 2019-20. In the previous FY 2020-21 life achieved 38.78 heats and the current FY 2022-23 the cumulative life is on increasing trend of above 47 heats. The average campaign life of back up casting achieved 18. During de-bricking of refractory bricks by heavy rock breaker, the partial damaged backup castable were being reinforced by conventional castable before safety bricks lining during the next campaign capital repair work.

Conclusion:

The steel ladle backup permanent lining carried out by self-flow monolithic refractory castable provided better result compared to the relining by insulation bricks and high alumina bricks.

Acknowledgement: BSP, SAIL Management; Refractory Engineering Department; RDCIS, SAIL Ranchi Unit; SMS-III Project; SMS-III and all the departments related to the stabilization of SMS-III Steel Ladle in Bhilai Steel Plant, SAIL.

Design of the State-of-Art Technology of RH Snorkel and its Performance

Soumen Jana*, S. Satpathy, A. K. Samanta, H. Nagata. S. Sengupta, P. B. Panda

TRL Krosaki Refractories Limited, Belpahar – 768 218, Odisha (INDIA)

Abstract:

Selection of Refractories for RH degasser particularly for snorkel is very critical and important as this equipment is used in severe operating conditions. The overall performance of RH degasser depends basically on three parameters. One is the direct bonded magnesia chrome (DBMC) brick quality, second is the design of Al_2O_3-$MgAl_2O_4$ spinel castable and third is its metallic shell and anchor design. At the same time the quality of repairing material particularly gunning mass is equally important to enhance the snorkel life. TRL Krosaki has done a lot of work in all the above areas and is capable to select or design the best quality refractories to get satisfactory performance based on operational parameters and grade of steel. Some of the plant produce more electric grade steel which is very corrosive to DBMC bricks. But the development of one special quality DBMC brick can withstand such severe operational parameters. Requirement of castable is also studied in detail and accordingly suitable castable is designed having excellent thermo- mechanical properties along with very good spalling and slag corrosion resistance. To improve the performance further it is suggested to reinforce the castable with the introduction of steel fiber. Cooling of metallic shell is also mandatory to prevent the stability of the whole structure. One special kind of shell design along with cooling effect help to enhance the performance. While assembly of the bricks it is essential to make it with zero gaps in between to prevent the slag/metal penetration.A high precision equipment is used for grinding the surface of the bricks, in order to ensure assembly of the bricks with zero gaps and no mortar.

In this paper, the details properties of DBMC bricks and Al_2O_3-$MgAl_2O_4$ castable are discussed. The assembling technique is also discussed while providing some pre-assembled snorkel with proper installation. Finally, the performance of snorkel is discussed at different plants having different operational parameters

Introduction:

RH degassing technology is used in secondary steelmaking stage mainly for manufacturing of auto-grade and higher-grade steels. The process of vacuum degassing of steel in steel ladle has the purpose of reducing the content of harmful gasses dissolved in steel as hydrogen, oxygen, nitrogen, as well as decarburizing and raising steel purity, thus improving its mechanical properties. To complete this entire refining process, Snorkels are used for production of cleaner steel. Snorkel is a complex refractory assembly which is inner lined with bricks and outer lined with castables over the cylindrical steel core shell to sustain high temperature (Fig.1).

injected into the inlet snorkel to increase the molten steel velocity entering inlet snorkel.

Faster operations and the ability to perform gas removal, decarburization, desulphurization, and alloy addition with precise composition control makes RH degassers superior to other metallurgical equipment like the vacuum arc degasser.

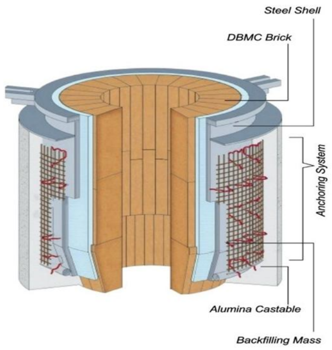


Fig. 1: Schematic Diagram of RH Snorkel

Design of DBMC brick

Refractories used in the lower vessel and snorkel interior of RH degassers suffer erosion due to contact with rapidly moving molten steel (100-150 metric ton/min) at 1480- 1630°C. The chemical reactions in the RH vessel like decarburization and degassing, the violent temperature change, the O_2 blowing and vacuum conditions, etc. In particular, the RH process for high Mn and high Si steels causes more severe corrosion conditions for the RH refractory lining. As the decarburization reaction proceeds, the amount of FeO concentration decrease and after decarburization reaction addition of Al to deoxidize the molten steel decrease the FeO content in slag and Al_2O_3 in slag. FeO is known to be aggressive towards most of the typical refractory lining materials. During the Al addition, the reducible components in the slag are reduced by Al and slag becomes mainly $CaO–Al_2O_3$ [4-5]
Wear rate of bricks inside snorkel and lower vessel is severe due to the abrasion caused by the high circulation rate of treated molten steel, thermal and structural spalling by the violent temperature changes, high corrosion by the Fe-oxides containing siliceous slag and CaF_2- riched desulfurization powders attack, leading to degradation of texture by the vaporization of refractory components in vacuum and in oxygen blowing. The inlet snorkel suffers severe abrasion due to argon gas injection. Additionally, hour-long intervals of cooling between operation cause thermal shock damage (ΔT = 800-900°C). Direct-bonded magnesia-chrome ($MgO-Cr_2O_3$, DBMC) refractory containing 18-28 wt% Cr_2O_3 is most suited for this application because it is dense (Apparent porosity 11%-18%), has a high hot modulus of rupture (HMOR) of 4-9 MPa at 1500°C and has superior resistance to corrosion and thermal shock damage. [1-3]

High quality DBMC bricks fired at high temperature (>1800°C) with low porosity and high HMOR ensured through sophisticated mixing and pressing are used in assembly of snorkels. Typical physical and chemical properties of bricks are summarized in Tab.1. Upon subjecting to spalling resistance test at 950°C to air, no cracks are observed up to 30 cycles as shown in Fig.2.

Fig.2 Appearance of DBMC brick after Spalling

Tab. 1: Typical Properties of DBMC brick

Parameters	Typical Values
MgO (%)	56.7
Cr_2O_3 (%)	25.2
Apparent Porosity (%)	15.2
Bulk Density (gm/cc)	3.31
Cold Crushing	75.4

Strength(MPa)	
HMOR (MPa) at 1500^0C	8.2

Design of Al2O3-MgAl2O4 Castable:

To achieve the satisfactory performance of snorkel, the quality of Al2O3-MgAl2O4 spinel castable is equally important like DBMC brick. The special features for spinel containing castables should have (a) excellent slag corrosion resistance (b) high mechanical strength (c) volume and structural stability at application temperature (d) good thermal shock resistance
(e) reduce tendency for crack formation in application and (f) limited infiltration of slag at high temperature. To fulfill the special requirement for snorkel one new Al2O3-MgAl2O4 castable has been designed while introducing a special material in matrix having dual purpose. It gives better slag corrosion resistance as the super fine spinel particles are uniformly distributed in matrix and thus prevent slag corrosion. At the same time this material is having CA and CA2 phases exhibiting hydraulic properties.

The requirement of castable for single snorkel is very high and casting duration is also long and therefore the first essential property of this castable is flowability and working time. The free flow of this castable is shown in Fig. 3 upto 90 minutes the free flow is > 250 mm.

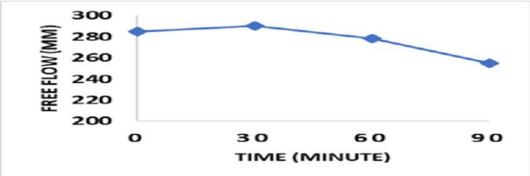


Fig.3 Free flow of Al2O3-MgAl2O4 Castable

AP values are mentioned in Fig. 4 and it is observed that this castable shows lower porosity after drying. Lower AP is achieved due to proper grain size distribution and selection of maximum grain of higher size than conventional castable. The decrease in AP is observed while firing from 1500^0C to 1600^0C, is due to sintering of castable.

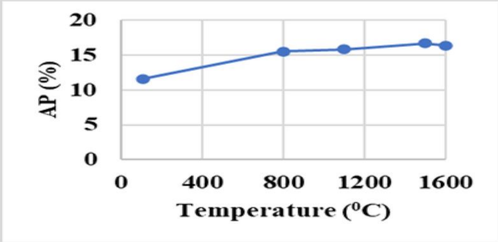


Fig.4 Variation of AP with temperature

Measurement of CCS is very important as this specific castable is designed without cement. One special material was introduced in recipe having CA and CA2 phases and responsible for strength development after drying as well as after firing as shown in Fig. 5. Though cement is not there, CCS of this castable is in the same range like other castables having cement.

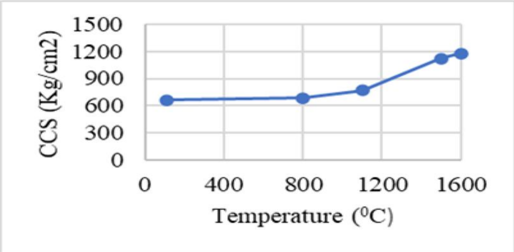


Fig.5 Variation of CCS with temperature

The volume stability of this castable is very important from the viewpoint of application. Shrinkage is not allowed as it leads to cracking followed by chipping out and fall-out of castable during operation.

Fig. 6. Repeat PLC measured at 1600^{0}C

To understand the volume stability, this castable was repeatedly fired at 1600^{0}C for five times and change in PLC was measured. The observation is shown in Fig. 6.

In repeat firing there is always positive PLC. The values are almost in the same range or slightly in higher side with more cycle of firing. This behaviour indicates it is having better volume stability which will help to prevent crack formation as well as propagation during application.
Spalling resistance is another important parameter and it was measured as per DIN method from 1300^{0}C to water quenching with a sample of size 50 mm dia and 50 mm height. In Fig. 7, the appearance of both regular castable and specially designed castable is shown after 26 cycles. The regular castable was disintegrates into several pieces (Left side) whereas the specially designed castable was in a good condition except one small crack formation. Ultimately the specially designed castable disintegrated after 64 cycles. This behaviour of specially designed castable supports that it is having better thermal spalling resistance than regular one and suitable for snorkel application.

Fig. 7. Thermal spalling test after 26 cycles

HMOR was measured at 1400^{0}C and 1500^{0}C and shown in Fig. 8. Before measurement HMOR, the samples were pre-fired at the corresponding temperatures with three hours soaking. There is improvement in HMOR both at 1400^{0}C and 1500^{0}C for specially designed castable against regular one.

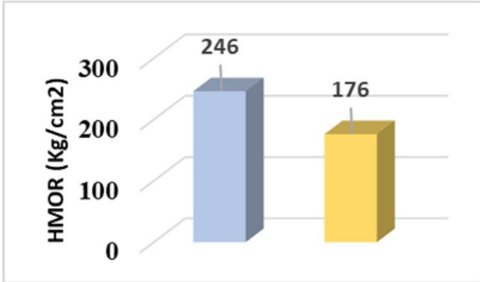


Fig.8. HMOR at 1400^{0}C (Left) and 1500^{0}C

This may be due to design of this castable without cement. Of course, there is CaO in the system, but the source is different other than cement.

Assembly of bricks for snorkel manufacturing

Surface grinding of individual bricks is done in highly automated and sophisticated grinders with high precision grinding (Fig.9). Individual bricks after grinding are placed one after another on a base plate to make ring assembly with zero gaps in order to ensure no metal penetration during application (Fig.10).
To make zero gaps in between the bricks it is essential to grind the surface of bricks in micron level. Also, at the same time there should be enough strength in between the bricks without any mortar joints.

Fig. 9: Bricks after surface grinding

Fig. 10: Assembly of bricks without mortar

The final apperance of ring assembly is shown in Fig. 11 where there are no gaps. This brick assembly is used inside the snorkel during manufacturing.

Fig. 11: Final appearance of brick ring

Snorkel is a composite structure of DBMC bricks, Spinel castable, metallic shell along with different anchors. Due to different components, it is very much essential to pre-heat it with proper heating cycle and soaking time. TRL Krosaki has designed a specific heating cycle with an optimum temperature profile in such a way so that there are no surface cracks after pre- firing. The appearance of snorkel after pre-firing is shown in Fig. 12. Finally, surface finishing of snorkel is done before dispatch as shown in Fig.13.

Fig. 12: Appearance of snorkel after pre- firing

Performance at different customers:
Snorkels manufactured in TRL Krosaki are used in various steel plants with different operational parameters. Table.2 shows the performance of snorkels used in few steel plants.
Fig. 14 & 15 shows the appearance of snorkel after 1st heat and 31st heat during operation.

Tab.2. Performance Data of Snorkel

Parameters	Vacuum Treatment Time (Min)	Avg. Life (Heats)
Plant- A	33	65
Plant - B	17	103
Plant - C	25	117

Fig. 13: Appearance of snorkel after surface treatment

Fig. 14: Appearance of Snorkel after 1st heat

Fig. 15: Appearance of Snorkel after 31st heat

Conclusion:
Proper selection of bricks, castable and manufacturing of snorkel assembly is important for performance of snorkel

refractory in steel plants. TRL Krosaki is well equipped with superior quality DBMC brick manufacturing press and kilns, high intensity monolithic mixers and highly automated surface grinders for brick assembly. With this state-of-the-art technology, Snorkels being an assembly product, manufactured under a single roof, have the capability to withstand severe operating conditions at different integrated steel plants.

REFERENCES

1. Mandal S, Dileep Kumar CJ,Kumar D, et al. Designing environment-friendly chromium- free Spinel-Periclase Zirconia refractories for Ruhrstahl Heraeus degasser. J Am Ceram Soc.2020; p.1–20.

2. Cho MK, Van Ende MA, Eun TH, Jung IH. Investigation of slag-refractory interactions for the Ruhrstahl Heraeus (RH)

3. Vacuum degassing process in steelmaking. J Eur Ceram Soc.2012;32(8):1503–17

4. Martino M, Curletto L, Bonifacino V. Some correlations between composition and characteristics in the field of chrome-free refractories for steel degassing. Paper presented at the Unified International Technical Conference on Refractories; November 4–7, 2001; Cancun, Mexico.

5. Bi Y, Smith IA, Andreev K. Development of degasser snorkel refractoriesand the effect of the process parameters on wear rate.In: Goski DG, Smith JD, editors. Proceedings of the Unified International Technical Conference on Refractories. Victoria, BC, Canada: The American Ceramic Society; 2013. p. 755–9.

6. Czapka Z, Skalska M, Zelik W. Mechanisms of wear of refractory materials in snorkels of RH degasser and the possibilities for their reduction. In: Smith JD, editor. Proceedings of the Unified International Technical Conference on Refractories. Orlando, FL: The American Ceramic Society; 2005. p. 19–23.

Stabilization of RH degasser in SMS-III, Bhilai Steel Plant, SAIL

Jitendra kumar , Amit Roy , Pronab Roy
Bhilai Steel Plant, SAIL
[a] Corresponding author's email: jitendrakumar2@sail.in

Abstract

In Bhilai Steel Plant, SAIL, SMS-III shop comprises of one RH degasser unit for production of ultra-low Carbon, low Hydrogen steel with average heat size 165 Ton. The principal function of RH degasser unit is removal of gases like H2, N2, O2 etc., natural decarburization, forced carburization with top oxygen blowing lance, liquid steel composition adjustment by addition of alloys, temperature adjustment and making clean steel as per customer requirement. The first heat through RH degasser was taken on dated 08.10.2018. From FY 2018-19 to FY 2021-22 the RH degasser unit of BSP SMS-III has gone through average life of 44 heats to 81 heats respectively and in FY 2022-23 cumulative average life is 91 heats upto August 2022. From the initial starting phase to current status RH degasser unit has been stabilized along with the shop. This paper is about the stabilization of RH degasser in SMS-III, Bhilai Steel Plant (BSP), SAIL.

Keywords – RH Degasser; Stabilization; SMS-III; BSP-SAIL

INTRODUCTION

The RH Process was developed by Rheinstahl Heraeus Shutte at Hattingen, Germany in 1957. It has since been improved, particularly by the Hirohito Works of the Fuji Iron and Steel Co., Japan. Degassing is elimination of dissolved gases from liquids. There are three types of degassing, ladle degassing, stream degassing and circulation degassing. In ladle degassing liquid steel is held in a ladle which is put inside a vacuum chamber. Steel may be stirred by bubbling an inert gas while being exposed to vacuum. Whereas, in stream degassing liquid steel flows down in the form of a stream from the furnace or ladle to another ladle or mould during its exposure to vacuum. In circulation degassing liquid steel is either continuously or intermittently circulated during its exposure to vacuum. RH degasser is being operated through circulation degassing.

Brief Description of shop SMS-III, BSP, SAIL:
SMS-III shop BSP, SAIL has been designed with capacity of 180/165 Ton. The shop consists of 3 BOF LD Converters, 3 ladle furnaces, one RH degasser unit, two six strand radial billet casters, one six strand radial bloom cum billet caster and one three strand radial beam blank caster. Through RH degasser the shop has successfully produced special steel grades like Gr R-260E1, 1175HT, NCC Rails.

Issues during stabilization of RH Degasser:
RH degasser snorkel life was very less. Average life of RH snorkel was 44 heats in the first FY 2018-19. Preheating was improper after refractory relining of the RH vessel. The heating process in auto mode as per heating schedule had not resulted desired preheating of the vessel. The snorkel inside and outside refractory observed same color as was during the relining in cold status. The preheating process was shifted to manual mode from auto mode and resulted proper preheating. The lower leg and bottom ramming work were being executed initially by ramming mass. During refractory relining work it was observed that the ramming after placement of lower leg was not happening properly through hydraulic rammer. In place of ramming mass self-flow castable was being used in one vessel. During application it had been observed that the gap between the lower leg and snorkel vessel was filling properly by the

castable. Further it was observed through cutting bricks as per vessel condition and requirement the filling of monolithic refractory can be made better and resulted better life.

The gunning activities are one of the major part to achieve snorkel life of RH degasser. Initially the gunning had been carried out by the gunning car through automatic machine. Along with the shop stabilization to speed up the treatment completion in RH and sending the ladle for continuous casting, it had been observed that the manual gunning took less time than the automatic gunning car. However, during initial manual gunning, the mixing of water and gunning material along with the pressure control were not proper and observed during the starting of the gunning, there was material wastage and housekeeping issues. One designated tray had been kept nearby the vessel to standardize the mixing work first and then start gunning for the RH snorkel.

At the beginning of the shop welding failure observed in the vessel. The down vessel used to check for any kind of shell crack and welded. After welding and relining the vessel, puncture observed from the previous welding joint area. The welding work improved along with starting of UT test. Initially it was a very simple way to pour water on the welded shell to check whether any minute drop of water was coming out from other side of the shell from the welding area. From last two years DP test started as per requirement. Initially MS electrode was being used for welding. After starting the use of LH electrode improvement in welding work observed. The connecting plate thickness had been increased and deformation of the connecting plate had been reduced. As a result welding failure in between snorkel and vessel joint has been minimized.

Initially the degassing temperature for high carbon heats (Rail Heat) was around 1580-85 o C. now it has been reduced to 1565-70 0 C. as a result refractory erosion reduced and snorkel life increased.

At the beginning of the shop the slag volume ladle was higher side. Due to higher slag volume snorkel was getting damaged. By the application of slag arrestor in the converters slag volume in ladle has been reduced resulting increase of snorkel life.

At the initial phase of the shop, after preheating of RH degasser, vessel setting with the offtake could not be executed properly. As a result vacuum inside the vessel, could not be achieved as per requirement. Also, after down of the vessel, RH offtake retainer plate area bricks used to be found damaged. Then it was observed that the vessel top cone area bricks were affixed with the offtake refractory. After analyzing the root cause, it was found that, after preheating vessel top cone bricks used to be expanded resulting the above problems. To solve the problem, top cone vessel refractory relining pattern modified with monolithic refractory material along with ceramic fibre. After the use of monolithic refractory and ceramic fibre, the problem has been resolved.

Acknowledgement: BSP, SAIL Management; SMS-III Project; SMS-III; Refractory Engineering Department and all the departments related to the stabilization of SMS-III RH degasser in Bhilai Steel Plant, SAIL.

Thermo-Mechanical Modelling & Simulation for effective Refractory Design in Iron & Steel Industries

Kushal Agarwal[1,a], G S Debasisha[1], Pranoy Ku. Dubey[1], Tapas Shyamal[1], Debasish Sarkar[2]
[1] Sarvesh Refractories Pvt. Ltd., Rourkela, Odisha
[2] Department of Ceramic Engineering, NIT Rourkela, Odisha
[a] k.agarwal@sarvesh.com

Abstract

The paradigm shift towards a systematic and high-end technical approach is mandatory for adaptation and ensuring consistent performance. While development and performance analysis are concerned, herein, the main focus is given on the torpedo ladle refractory lining design in the iron making area and the throttling impact on slide gate refractories in steel making area.

Refractory thickness optimization by maintaining shell temperature is always a challenge in torpedo ladle lining. Here, a heat transfer-based model using *Simu-therm* & *ANSYS* is considered to optimize refractory lining thickness by maintaining a shell temperature within an allowable limit and the effect of using an insulation board against a steel shell has been evaluated.

In steelmaking, throttling is considered the most critical operation to affect the refractory life of the collector nozzle during steel flow through slide gate refractories. A Computational Fluid Dynamics (*CFD*) based model that compares negative pressure, flow pattern, and streamlines velocity with different opening ratios at the junction of the slide gate top and the bottom plate has been presented to evaluate the throttling effect on the slide gate refractories.

Adapting such technology-based modelling and simulation ensures adequate safety and performance during operations in Iron and Steel making processes.

Keywords – torpedo ladle; insulation; thermal conductivity; slide-gate; throttling; flow simulation

INTRODUCTION

Modern steel making process has a mandatory involvement of critical shaped and unshaped refractories in almost all stages such as: iron making, primary steel making, secondary steel making and continuous casting [1]. Due to the high complexity of the involved processes, modelling and simulation tools are being adopted as a key asset to design effective refractory bricks for lining of iron and steel making furnaces and functional refractories for flow and turbulence control. The key goal of such modelling and simulations is the assessment of refractory designs to develop durable and long-lasting solutions for different operating conditions [2]. Simulation tool are used to determine the temperature profile in the refractory lining for the calculation of thermal expansions, to calculate thermo-mechanical stress developed in the refractory due to various operational parameters, to check flow behaviour of molten steel during continuous casting, to estimate the wear for different temperatures and slag compositions [3,4].

This article focuses on use of modelling & simulation tools: *(A)to study the effect of using insulation board in the refractory lining of torpedo ladle* and *(B)to evaluate the impact of throttling in ladle slide gate refractory elements*. Multiple commercial software packages have been engaged in this study, such as *SIMU-THERM8.0* for thermal profiling & calculation, *ANSYS Mechanical* for heat-transfer modelling and *ANSYS Fluent* for steel flow simulations.

A. The effect of using insulation board in the refractory lining of torpedo ladle:

Torpedo ladle is widely used in the transportation of molten iron from blast furnace

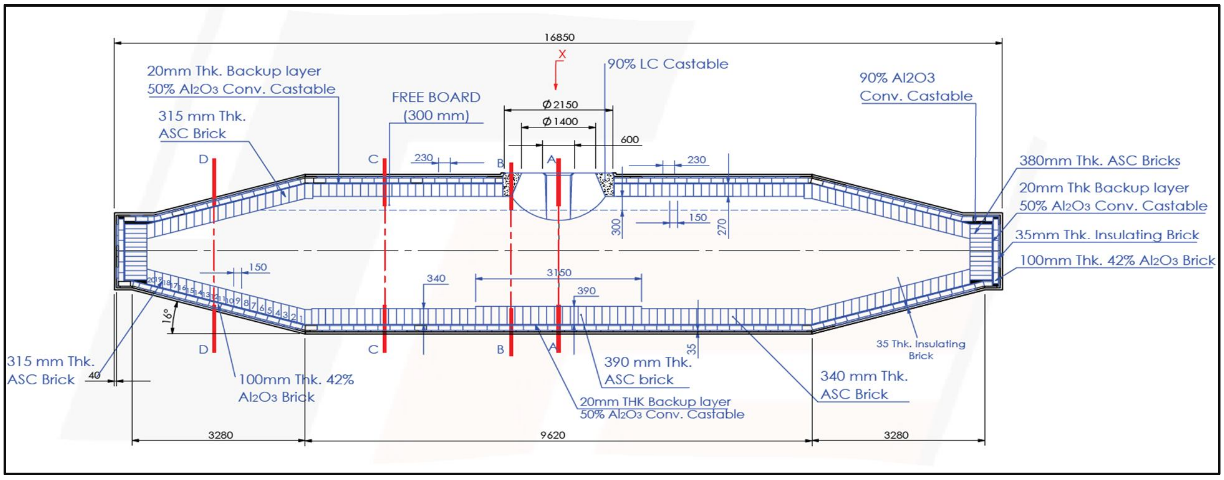


Fig-1.1: Refractory Lining design of 340T Torpedo Ladle

to converter because of its better thermal insulation compared to other ladles. The lining of these vessels is made of different types of layered refractory and insulating materials that can maintain molten iron temperature for long hours.

The working lining being the Alumina-Silicon Carbide-Carbon (ASC) bricks provides a better ability to absorb thermo-mechanical stress, thus reducing irregular wear due to cracks. This also provides excellent resistance to thermal shock and slag corrosion at the cost of unwanted high thermal conductivity [1]. Adding suitable back up insulation reduces the shell temperature, so providing the following benefits: reduced skulling; minimised risk of break out (through reduced shell deformation); accommodation of variation in tapping temperatures, and increased residence time and safety.

The hot face bricks (ASC) gradually reduce in thickness during operation of the torpedo ladle. A prerequisite back-up insulation can balance the thermal profile. The back-up insulation must withstand the increasing thermal and mechanical stresses. A superior back up insulation allows low shell temperature and reduces the wear lining in operation. A thermal model using *SIMUTHERM* and finite element-based model using *ANSYS* is considered for introduction of a ceramic insulation board of suitable thickness in the refractory lining to allow the working layer bricks to operate efficiently at reduced thickness by maintaining low shell temperature.

Since metal impact area of barrel region have higher erosion rate, this study focuses on the same zone as highlighted in ***Fig-1.1*** and the same region is shown in ***Fig-1.2*** separately.

Lining pattern at Barrel region of Torpedo ladle			BD (kg/m^3)	TC (W/mK)
A	Shell	45 mm	7850	48.8
B	Insulation Bricks	35 mm	1000	0.41
C	42% HA Bricks	100 mm	1200	1.6
D	50% Conv. Castable	20 mm	1300	0.43
E	ASC Bricks	390 mm	2980	3.72

Table-1.1: Lining pattern at Barrel region and material properties

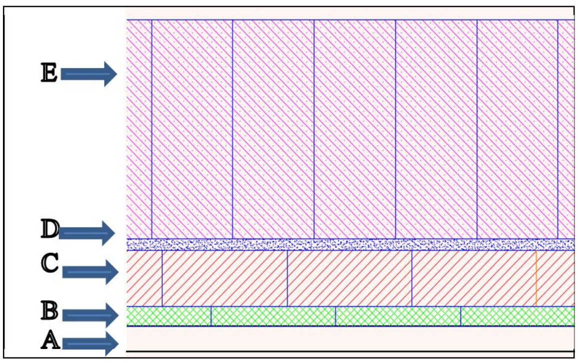
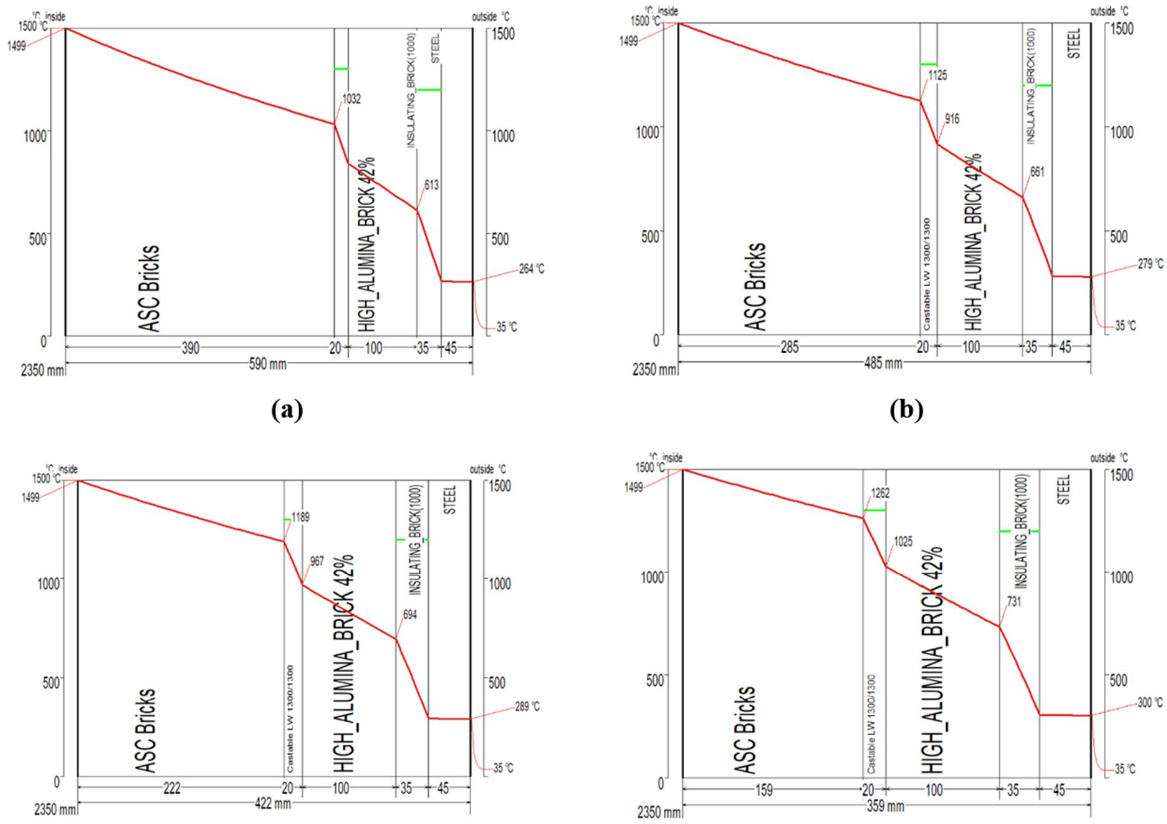


Fig-1.3: SIMUTHERM screen shows thermal condition of both outside(shell) and inside (hot face)



(a) (b) (c) (d)

Fig-1.4: Temperature profiles of refractory lining without insulation board (a) at beginning of campaign, (b) at life of 500, (c) at life of 800 , (d)at life of 1100

As per the data set collected from number of campaigns at different *SAIL* unit, the wear rate of ASC bricks was taken as 0.21 mm/heat at the impact pad area. Considering above material properties and wear rate below are the observations on shell temperature of torpedo ladle. The thermal profile is drawn using SIMUTHERM based on the material properties provided in Table-1.1 and the thermal conditions shown in ***Fig-1.3***.

Based on the thermal calculation and the thermal profile shown in ***Fig-1.4***, it can be observed that with reduced thickness of wear lining (ASC Bricks), the shell temperature rises significantly and it reaches 300 ^{o}C at a life of 1100. Targeting shell temperature of 300 ^{o}C as safe operational temperature for current lining pattern, the campaign shall end at life around 1100 with a remnant thickness of working lining brick 159 mm.

Addition of high-porosity insulation board in existing lining pattern:

With the aim of achieving higher campaign life utilizing the remnant thickness of the wear lining, a high-porosity insulation board is introduced to the lining pattern and the thermal observations are as follows.

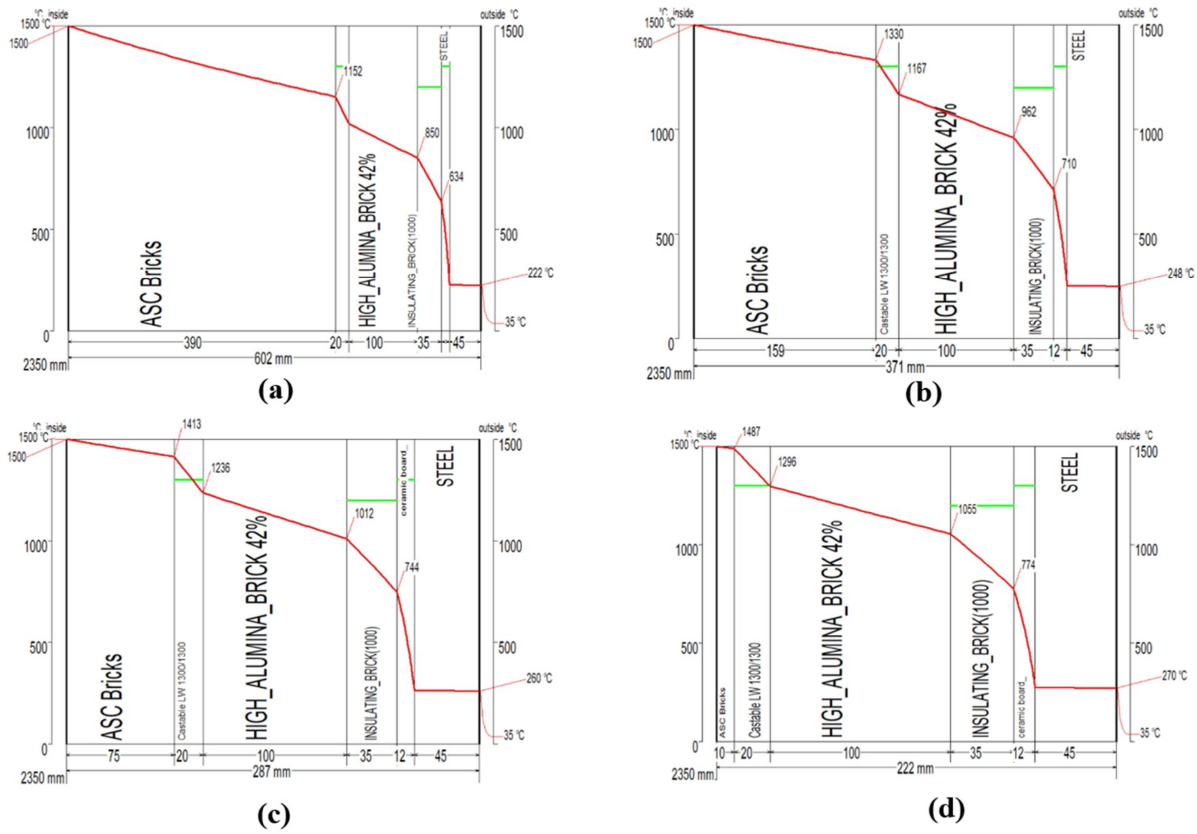


Fig-1.5: Temperature profiles of refractory lining with insulation board (a) at beginning of campaign, (b) at life of 1100, (c) at life of 1500 , (d) near to worn-out stage of ASC bricks

From ***Fig-1.5***, it can be easily observed that the introduction of an insulation board into the refractory lining helps stretch the campaign beyond 1500 heat by probable shell temperature below 280 °C even after complete

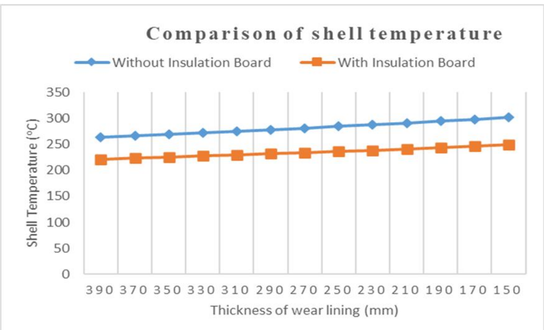


Fig-1.6: Shell temperature comparison

erosion of wear lining. Shell temperature comparison for two cases is shown in ***Fig-1.6.***

To verify the result of the SIMUTHERM model, Finite Element Analysis (FEA) based modelling using ANSYS is taken
into consideration.

FEA Modelling:

Geometry Modeller of ANSYS Workbench is used to prepare the geometry as shown in ***Fig-1.7*** of torpedo ladle and refractory layers using dimensions shown in ***Table-1.1***.

Modelling Assumptions:

The initial conditions are taken as follows: the temperature of molten iron is considered to be homogeneous. The mass transfer is ignored among molten iron and refractory lining. Thermal conduction in the refractory linings is the only medium of heat transfer.

Characteristic values of the thermo-physical properties of the various materials used to make torpedo linings are represented in ***Table-1.1***.

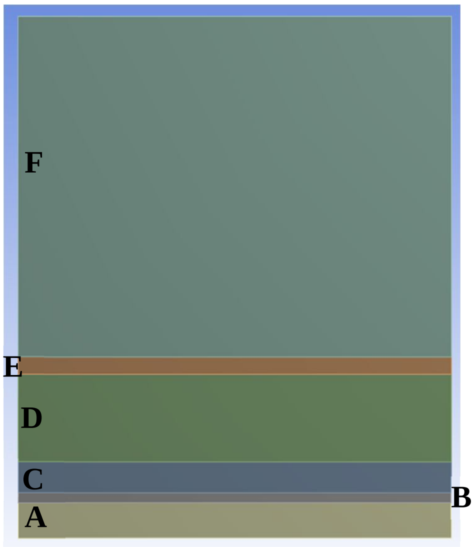


Fig-1.7: Geometry for Refractory layers

Since the accuracy of the results depends on quality of meshing elements, hexahedral type of mesh was tried as shown in ***Fig-1.8*** and it consist of total 1015570 nos. of nodes and 223132 nos. of elements.

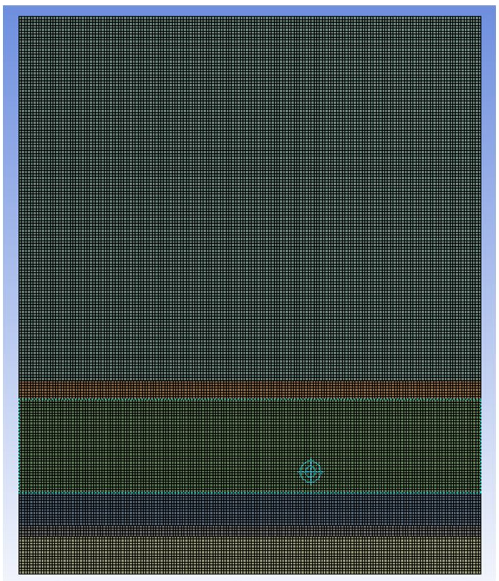


Fig-1.8: Meshing geometry

The same thermal condition (***Fig-1.3***) for inside and outside is assigned in ANSYS interface and the model was solved for Temperature contour using the commercial software package ANSYS, as shown in ***Fig-1.9.***

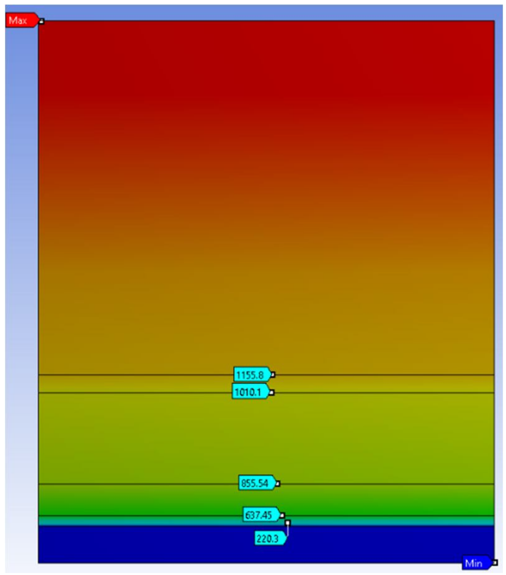


Fig-1.9: Contours of temperature

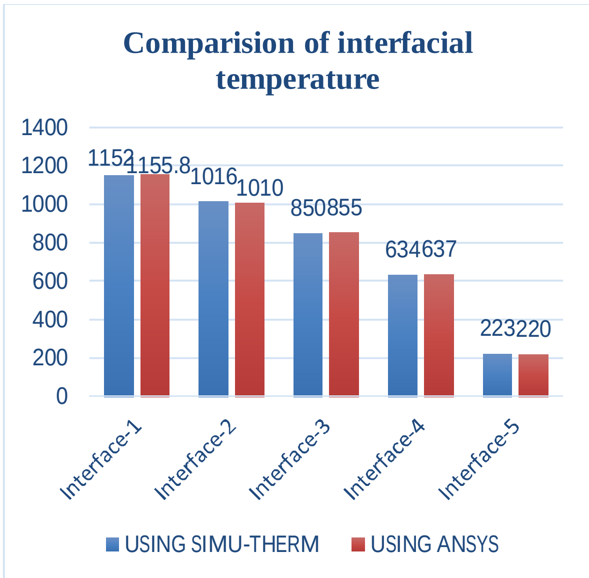


Fig-1.10: Temperature at each interface of torpedo lining

Temperature values found at each interface of the refractory layers in FEA modelling (***Fig-1.9***) was compared with the values that were found in SIMUTHERM with the same material and geometry condition and presented in ***Fig-1.10***.

Thermal insulating materials with lower thermal conductivity can be used as a thermal insulation lining just after the steel shell. In this research work, a calculation-based thermal model using SIMU-THERM and FEA-based thermal model is established to evaluate the advantages of using an insulation board during torpedo ladle lining. According to the results of the modelling, the use of an insulation board can efficiently maintain the shell temperature below the specified limit restricting the heat loss and improving the campaign life. Hence the benefits of the nano-porous thermal insulating board of suitable thickness for the torpedo ladle are fairly considerable.

*B. **The impact of throttling in ladle slide gate refractory elements:***

During the continuous casting process of modern steelmaking, the molten metal flows from the ladle to the tundish and continuously from the tundish to mould. This molten metal flow transfer is a key operation of continuous casting which strongly affects the quality of steel due to the air aspiration in molten metal causing non-metallic inclusions generation through reoxidation [1].

Air aspiration occurs due to negative pressure (i.e., below atmospheric pressure) generated near the narrow opening regulated by the flow control system i.e., ladle slide gate (between ladle and tundish) or stopper rod (between tundish and mould). To control the flow parameters from the steel ladle and to maintain the tundish level, the slide gate has to be operated in a throttled position which causes severe asymmetric flow below the throttling region. A 3-dimensional CFD-based model is established using the commercial software ANSYS Fluent to evaluate the impact of this throttled position on refractory.

Model Geometry: Slide-Gate System -

The model was demonstrated using the example geometry shown in ***Fig-1.11***. The flow channel from steel ladle to tundish consists of Well-block, Upper-Lower Nozzle, Top Plate (fixed plate), Bottom Plate (slide plate), Collector nozzle and shroud.

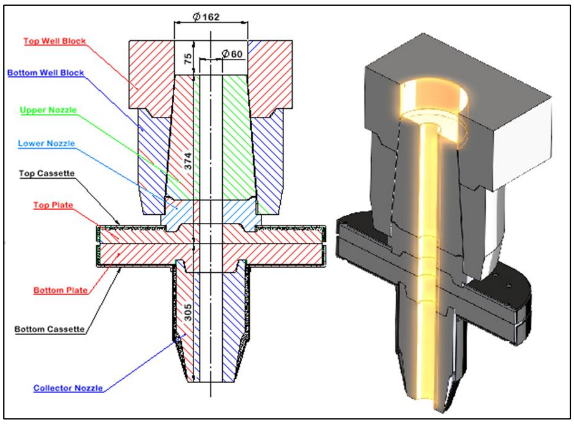
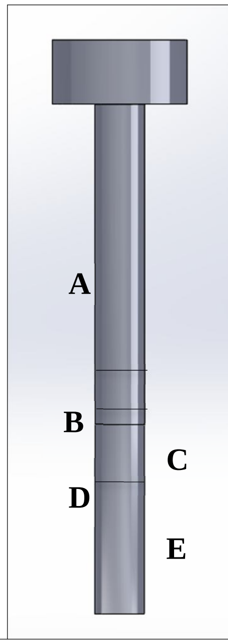


Fig-1.11: Ladle slide gate flow channel

Here in this study, the flow channel is considered from well-block to collector nozzle except ladle shroud. The bore diameter of the channel is 60 mm and the total height is 754 mm.

The flow geometry extraction technique is applied to ease the complexity of simulation and the extracted geometry is shown in ***Fig-1.12.***



A- Upper Nozzle
B- Lower Nozzle
C- Top Plate
D- Bottom Plate
E- Collector Nozzle

Fig-1.12: Extracted flow region geometry

Three different gate-opening ratios are simulated in this study i.e., Case-1: At full open condition (Throttling ratio- 1), Case-2: At 75% open condition (Throttling ratio- 0.25), Case-3: At half open condition (Throttling ratio-0.5). The geometry for three cases is shown in ***Fig-1.13***.

The meshing of the geometry is defined with tetrahedral elements with a suitable body sizing option to keep the skewness value of the meshing nearer to zero to achieve the right quality of the mesh.

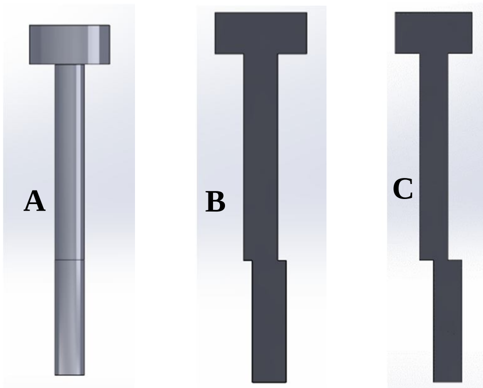


Fig-1.13: Geometry at (A)Full open condition (B)75% open condition (C)Half open condition

Boundary Condition and Solver Setting:

A pressure-based steady-state solver of ANSYS Fluent is engaged with a standard k-epsilon model to solve the model [5,6].

Inlet of the flow channel assigned with a mass flow type boundary condition i.e. 40 kg/s. and outlet is defined as pressure outlet. All three cases are simulated with the same casting speed and without clogging and erosion.

Result and Discussion:

In this particular simulation, the streamline velocity and negative pressure at three different opening condition is considered to evaluate the impact of the same on steel flow behaviour and refractory elements of ladle slide gate.

Comparison of streamline velocity & turbulence:

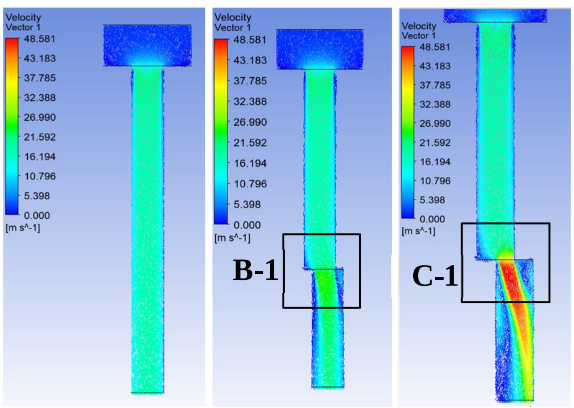
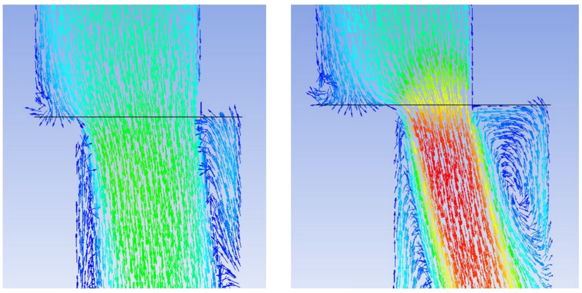


Fig-1.14: Velocity vector at (A)Full open condition (B)75% open condition (C)50% open condition

The velocity vector plot from CFD-Post (***Fig-1.14***) shows that the flow behaviour is symmetric and velocity is uniform in case of full open condition (***Fig-1.14, A***) while at the throttled condition(***Fig-1.14,B and C***) the flow behaviour seems to be asymmetric and has non-uniform velocity inside the flow channel.



View B-1 **View C-1**

This sudden change in velocity immediately below the throttled position creates heavy turbulence as shown in magnified view **B-1** and **C-1**.

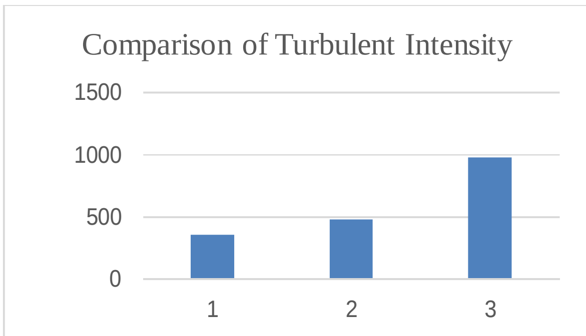


Fig-1.15: Comparison of Turbulent Intensity for Case-A, Case-B and Case-C

Compared to the full open condition(***Case-A***) the turbulence becomes 34% and 57% more for ***Case-B*** and ***Case-C*** respectively as shown in ***Fig-1.15.***

The flow asymmetry and higher turbulence below the throttled region i.e. at the collector nozzle may cause higher erosion at one side of the nozzle wall.

Comparison of Negative pressure:

The simulation result shows a pressure drop inside the flow channel below the throttled region when the opening area reduces and it creates negative pressure zone. The result of the pressure for three different cases is shown in ***Fig-1.16*** and ***Fig-1.17***.

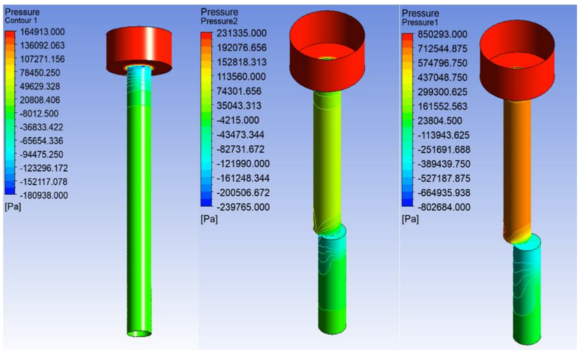


Fig-1.16: Contours of pressure for Case-A, Case-B and Case-C

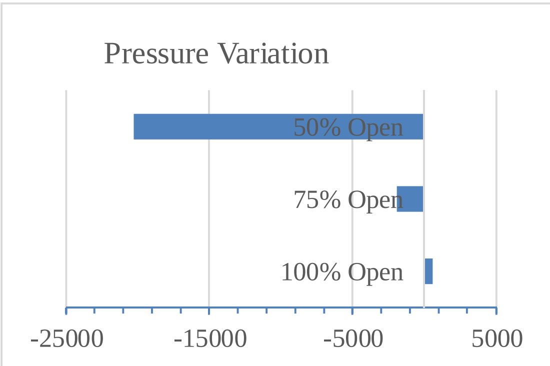


Fig-1.17: Comparison of pressure drop

The molten steel flow accelerates when area of cross-section of the slide-gate flow channel reduces due to throttling. According to Bernoulli's principle, the flow acceleration occurs simultaneously with a decrease in pressure since the pressure energy transforms into kinetic energy. Also, a loss in pressure occurs due to the sudden contraction and expansion of the flow control system of slide-gate. Due to the inertia effect of the accelerated flow, it can not adjust to the sudden cross-section change occurs due to throttling which results in pressure loss and flow separation. The total pressure drop is mostly affected by the opening area of the slide-gate system and other process parameters. When the pressure drop is very high, negative pressure generates inside flow channel resulting air aspiration through any minute gaps or cracks in the refractory components due to the pressure difference affecting quality of the steel.

Conclusion:

An additional insulation board facilitates refractory lining life and probable findings during FEA;

i. A 12 mm insulation board may contribute to life enhancement of torpedo ladle up to 1800 heats by maintaining shell temperature below safe operational limit depending on other operational parameters.

ii. A significant temperature change up to 220°C can achieve while working lining is 390 mm, and further, at the remnant thickness 159 mm, there is a reduction of 50°C in shell temperature.

iii. The result found from Simu-therm is verified by a FEA model and found to have a negligible variation.

CFD predicted the molten steel flow behavior through ladle slide gate and estimated the throttling effect in refractories, and the cumulative outcomes are;

i. At full open condition the flow behaviour is symmetric and have uniform velocity throughout the channel.

ii. At both throttled cases (i.e. at 75% and 50% open condition) the flow found to be assymetric and turbulent intensity becomes 34% and 57% more than that of full open condition which may severely affects the life of refractory component below throttled region.

iii. Generation of negative pressure below the throttled region may leads to air aspiration inside flow channel affecting quality of steel.

The application of modelling and simulation technology in refractory design reduces the chances of failure and contributes toward performance enhancement adding commercial values for refractory suppliers.

REFERENCES

[1] S. Biswas, D. Sarkar, "Introduction to Refractories for Iron and Steelmaking";Springer Nature, 2020.
[2] D. R. Kreuzer, C. Wagner, G. Unterreiter and J. Schmidl, "Refractory Design and the Role of Numerical Simulation"; The Minerals, Metals & Materials Society; 2018.
[3] Shiwei Liu, Jingkun Yu, Feixiong Mao, "Thermal Behavior Modeling of Interior Refractory Lining of Torpedo-ladle by Finite Element Method", Advanced Materials Research, Trans Tech Publications, Switzerland; 2011; Vols 282-283.
[4] S. W. Liu, J. K. Yu, L. Han, Z. Q. Li & Z. G. Yan, "Thermal insulation performance analysis of nanoporous thermal insulating materials applied in torpedo ladle"; Materials Research Innovations; 2014; VOL 18.
[5] Hyunjin Yang , Hamed Olia and Brian G. Thomas, "Modeling Air Aspiration in Steel Continuous Casting Slide-Gate Nozzles"; Metals; 2021.
[6] J. Rong, H. Jiang, L. M. Song and J. Li, "Effect evaluation algorithm of heat preservation improvement for torpedo car in Bao steel", J. Mater. Metall; 2006, 2, (5); 90–95.

Quality assessment of critical shaped structural refractory blocks using novel NDT technique

[1]Saumita Gangopadhyay, Monoj Halder, Prasanta Panigrahi, Navneet Sinha
Tata Steel, Jamshedpur
*saumita.gangopadhyay@tatasteel.com

Abstract

In iron and steel industry various critical shaped structural refractory blocks are used mainly in areas like flow control system, vessel sleeves etc. Performance of these blocks are paramount for smooth running of operation with less downtime. Hence evaluating the quality of these blocks before installation in plant is important. Ultrasonic pulse velocity technique can be used for checking the structural integrity and evaluating the physical and mechanical properties of the blocks. UPV method can easily detect any internal flaws/crack/ void present inside the material and gives qualitative idea regarding density and compressive strength of the material. This paper manifests the potential use of UPV technique for quality assessment of well block, vessel mother block and monoblock stopper.

Keywords -Ultrasonic Pulse velocity**;** crack; density; well block; monoblock stopper

Introduction

Refractories used in flow control system of steel manufacturing process are indispensable for maintaining streamline motion of liquid metal and constitute a vital part of the steel manufacturing process. Performance of these refractories significantly influence the quality of steel produced, production down time and production cost. Refractories used in flow control system are subjected to high abrasion and corrosion against the molten steel/slag and subjected to high thermal cycles during operation. Subjection to thermal cycles can cause nucleation of new cracks and propagation of existing cracks which limits the ultimate strength of these material and decreases their life. Hence detection of internal flaws/lamination and density variation is out most important for the smooth and safe running of the operation. Ultrasonic Pulse velocity method has the potential to detect any internal flaws present. Moreover, it can provide insight regarding the mechanical and physical properties of the material such as density, compressive strength, and low strain elastic modulus. Working principle of UPV technique is based on the mechanical wave propagation theory, transmission velocity of sound in a homogenous material is proportional to its square root of its density ρ and dynamic elastic modulus Edyn according to equation (1) and is independent of excitation frequency of the wave [1].

$$v = \sqrt{\frac{E_{dyn}\,(1-\mu_{dyn})}{\rho(1+\mu_{dyn})(1-2\mu_{dyn})}} \qquad [1]$$

where μ_{dyn} is dynamic Poisson ratio. Density variation within a single block or between similar parts of different blocks can be easily detected. In the presence of voids or crack inside the material, sound waves traveling through the material have to contour the cracks which lead to a significant decrease of velocity value. Hence ultrasound can be considered as a highly sensitive technique for internal crack detection and can detect microcrack up to 500μm.

From 1950s, Ultrasonic pulse velocity (UPV) method has attracted a lot of interest in civil construction for evaluating structural integrity of structural blocks because of its simplicity in operation and high accuracy in result. The technique is applicable where intrusive (destructive) testing is not desirable and can be applied to concrete, ceramics, rock, and wood. From 1960's, this technology has been adapted in refractory industry. At first, UPV method was employed only for specific applications such as fireclay coke oven bricks but from 1980's its application has been extended to bulk refractories. Study conducted by Boccaccini et al. showed quality control of refractory plates using UPV method [2]. Lafhaj et al. established an empirical correlation between porosity and permeability of mortar using this method [3]. Study was also conducted to determine thermal shock property of refractory material using UPV [4]. Sadeghi-Nik and Lotfi-Omran using UPV method have estimated compressive strength of fiber-reinforced self-compacted concrete [5]. Bentama et al. determined porosity of a clay membrane by passing ultrasonic waves through the structure [6].Another study shows material characteristics of alumina ceramics, e.g., porosity, Young's modulus and Poisson's ratio by UPV method[13]. Also, UPV test has also been used to determine delamination in ceramic tiles [7]. Literature studies point out that till date UPV test is mostly limited to research purpose in refractory field and very little work has been conducted for commercial aspect. The present work is conducted with the aim of (1) to detect any internal crack present in the well blocks, mother blocks and monoblock stopper (2) to evaluate their physical and mechanical property.

EXPERIMENTAL SET UP:

Ultrasonic test was conducted using a potable equipment (Proceq Pundit Lab-200). The equipment consists of two electro-acoustical piezoelectric transducers (pulse generator and pulse receiver) generating longitudinal waves. Elastic waves are generated by the pulse generator held directly on the surface of the refractory block. The transmitted waves are received by the receiver transducer and converts them into electrical signals. Coupling gels were used between the transducer and the refractory blocks for good contact and eliminate air gap between the two. Measurements can be taken in direct, semi-direct and indirect transmission modes as depicted in Fig2. Before testing the instrument was calibrated with a cylindrical bar of known thickness.

Fig1. PUNDIT instrument

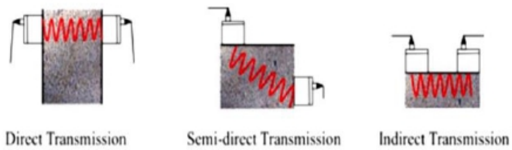


Fig 2. Modes of transmission

QUALITY ASSESSMENT OF WELL BLOCK:

Being fixed in the bottom of the ladle well blocks have to bear the ferro static load of liquid metal and have thermal gradient in longitudinal direction which may cause cracks in the structure during operation. Premature failure of well block limits the ladle campaign life. Two qualities of well blocks from the same supplier having similar dimension but different chemistry are used in LD#1 of Tata Steel. Assessment of these two qualities Q-1 and Q-2 were done using UPV method. Cylindrical Probes having diameter 50mm were placed on 15 identical points of the well blocks generating 54kHz frequency waves and at least 5 readings were taken at each point by direct transmission mode to reduced margin of error.

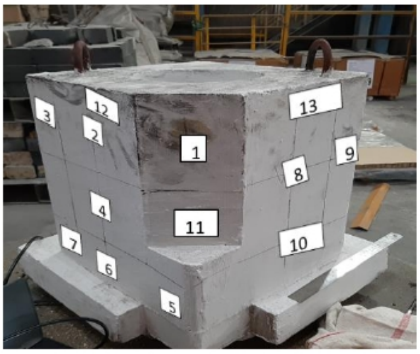


Fig 3. Points at which readings were taken.

Velocity value obtained from the qualities are plotted in the graph.

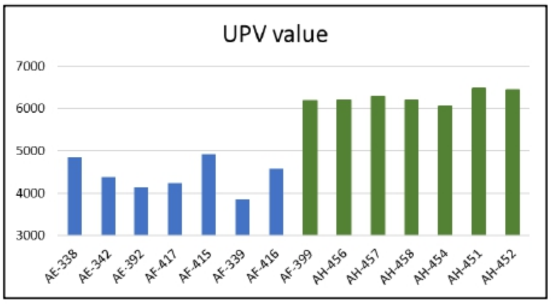


Fig 4. Velocity value obtained from two qualities of well block.

Blue and green color corresponds to qualities Q-1 and Q-2 respectively. The analysis shows significant velocity value difference between the two qualities, which suggests higher density and compressive strength of Q-2 than Q-1. Substantial decrease of velocity value had not been observed at any point which attributes the absence of critical size flaws inside these structural blocks. After service used well blocks were collected; density and compressive strength were measured and found in agreement with the density value.

Quality assessment of monoblock stopper:

Monoblcok stoppers are installed in tundish above the sub entry nozzle, the gap between the nozzle and the stopper head determines the through put of molten steel into the mould. Argon gas is injected into the liquid steel through the stopper tip, which increases pressure below the throttling point and prevents alumina build up in the casting nozzle. For the effective running of operation, stopper needs to fulfil several properties: high corrosion and erosion resistance, low wettability against steel- and slag-melts, high thermal shock resistance, as well as high mechanical strength and oxidation resistance at elevated temperatures. Stopper tip is the crucial area which is subjected to maximum corrosion and erosion. Body of the stopper is made up of alumina-carbon, while the nose is reinforced with different mix types- Alumina-C, MgO-C, Spinel-C. Glaze coating is provided on the surface to prevent oxidation of carbon. Sometimes extra reinforcement is provided in the slag zone area to prevent against corrosive action of tundish slag. The joint between the body and the tip is the most critical part of the stopper, any crack or internal defects present in the joint can migrate into the body during operation and may led to stopper failure. To measure the velocity of sound across the joint, cyclindrical transducers having 28mm and generating 150kHz pulse were placed on the body and the stopper head. Velocity was measured at 4points (0^o, 90^o, 180^o, 270^o) around the cross-section of the block. In this casestudy,total 9 stopper blocks from same supplier were evaluated by NDT method.

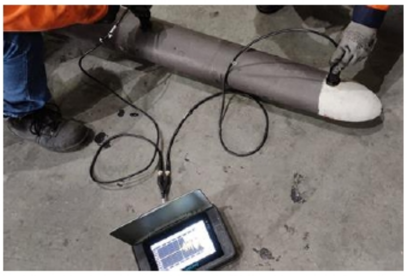


Fig 5. Position of transducer on the mother block.

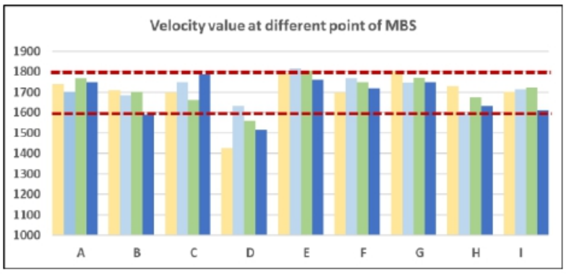
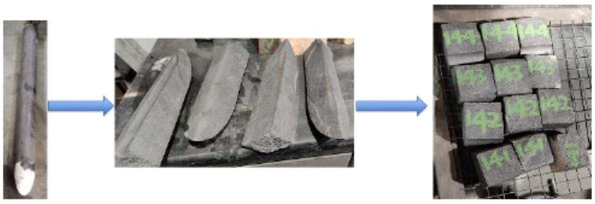


Fig 6. Velocity value at 4 different point of monoblock stopper.

From the graph it is evident that density of D stopper is comparatively lower and ununiform throughout the cross-section which may be due to un-uniform pressing/density variation during isostatic pressing of blocks.

As D is showing wide variation in velocity value , sample were collected and initially 300 mm length was cut from bottom (tip) , again this portion is cut into 4 pieces according to the NDT testing position . From each part 3 no's of AP,BD conducted to check the manufacturing uniformity (pressing).



Wide variation in BD is observed in different portion of MBS – it varies from 2.35 to 2.63 , which is also lower than specified norms – simultaneously AP also varies from 8 to 11 % .

All this results indicates variation at manufactures end may be material pressing is not uniform.

Similarly, UPV method is employed for assessmemt of tap hole system of LD vessel before relining.

CONCLUSION:

From the above work, it can be concluded that Ultrasonic pulse velocity method can be employed for qaulity assessment of critical shaped structural refractory blocks. Instances like presenece of any internal crack/flaws/lamination and density variation inside the block can be detected easily by measuring the velocity value at various point.

REFERENCES

[1] M. G. G. A. G. J. Alexandre Bogas, "Compr strength evaluation of structural lightv concrete by non-destructive ultrasonic velocity method," Ultrasonics, vol. 53, no. 962-972, 2013.

[2] M. M. b. M. C. a. I. D. c. M. R. a. C. L. a. A D.N. Boccaccini a, "A lifetime prediction m based on Cumulative Flaw Length Th Journal of the European Ceramic Society, v no. 6, pp. 1175-1186, June 2012, .

[3] M. G. b. A. D. a. M. K. c. Zoubeir Laf "Correlation between porosity, permeabilit ultrasonic parameters of mortar with va water / cement ratio and water content," C and Concrete Research, vol. 36, no. 4, pp 633, April 2006.

[4] M. R. E. K. P. V. C. L. G. P. D.N. Bocca "Determination of thermal shock resistan refractory materials by ultrasonic pulse ve

measurement," Journal of the European Ce
Society, vol. 27, no. 2-3, pp. 1859-1863, 20

[5] O. L. O. b. Aref Sadeghi Nik a, "Estimati
compressive strength of self-compacted co
with fibers consisting nano-SiO2 using ultra
pulse velocity," Construction and Bu
Materials, vol. 44, pp. 654-662, July 2013.

[6] A. E. G. a. J.-Y. F. b. Jilali Bentama a, "Ultra
waves for characterisation of clay membr
Desalination, vol. 206, no. 1-3, pp. 1-8, Fel
2007.

[7] T.-H. C. b. W. W. L.-S. Chan
"Characterization of alumina ceramic
ultrasonic testing," Materials Characteriz
vol. 45, no. 3, pp. 221-226, September 2000

Intelligent technologies for refractory spend management

Avijit Pandit[1a,] and Debesh Halder[1]
[1] *mjunction services limited*
[a] email: avijit.pandit@mjunction.in

Abstract

Technology has enabled high degree of effectiveness in spend management process through various levers e.g. connected process, automation, linking supply chain networks, tractability, Artificial intelligence (AI), data analysis and forecasting. Challenge of the day is to identify perfect confluence process & technology levers aligned to desired outcome.

Big data analysis & forecasting, Robotic process automation & use of AI all are useful levers in strengthening a sourcing process and making financial decisions. One need to start from objectivity of an underlying sourcing process, benchmark with industry standards, identify areas of opportunities and then reach out technology levers fit for complementing the same.

Keywords – Big data; Artificial intelligence, Robotic Process Automation, Digital sourcing

INTRODUCTION

Being a strategic item for Steel manufacturing & Refractory producers, Chief Procurement Officers (CPOs) have specific challenges in managing spend of Refractory & its raw materials. Cost maintenance, margins, consistency, continuity & traceability to name a few. The primary concern being 'cost / margins' the decision making need to be supported with:

a. Analysis of trends / Insights / Forecast
b. Coverage of all cost elements
c. Creating optimum competitiveness
d. Conformance & continuity including geo-political scenario.

A. GOAL ORIENTATION OF PROCESS AND TECHNOLOGIES:

Focus shall be on creating an objective orientated process and then identify technology to leverage the process steps. Efficiency of any sourcing decision depends on the following key attributes:

a. Assessment of demand supply scenario, When to buy
b. Setting of Price / Cost goal
c. Create perfect competition / Win-Win negotiation scenario

Once these objectivities are firm we can deploy for available tech-levers

A.1. TECH-TOOLS TO ASSESS DEMAND SUPPLY SCENARIO:

Reporting & forecasting tools essentially leverage demand supply scenario. However establishing right co-relation between dependent and independent variables often becomes key success factor for TCSR analysis and predictive analysis.

Major steps involved here are

a. Identification of dependent variables i.e. raw materials or commodities to be sourced. Identification of independent variables (i.e. cost elements, equivalent/alternative materials and macro inflationary factors).
b. Develop relationship models using simulations and back-testing the same using BI tools.
c. Data scrapping, warehousing & reporting.

Successful organizations use master data management tools, Robotic process automations & BI tools as tech levers to achieve highest level of efficiency.

A.2. TECH-TOOLS TO SET COST GOALS:

Though internal budgets acts as a baseline guidance for sourcing activities however those are majorly driven by legacy algorithm and thereby an information technology driven price benchmarking becomes very effective for decision making. Best practices use 'four point' price benchmarking mechanism which can be achieved through available technologies.

i) Index based
ii) Cost model based
iii) Peer / Alternate comparison based
iv) Historical data based

It's often observed decision of setting cost goals are biased by one or two of above mentioned mechanism. It's important to impose symmetrical weightage on each mechanism to set the cost goals.

AI based cost modelling tools offer programmatic evaluation of justifiable prices. In mjunction services limited we use our MDM platform to map major commodities with relevant indices & cost component structure. RPA tools are used for data scrapping from all dependent variables and indices to derive cost goals using an underlying algorithm.

A.3. TECHNOLOGY TO CREATE PERFECT COMPETITION / WIN-WIN NEGOTIATION:

A perfect competitive market is probably the most sustainable condition for sourcing over a longer time frame. In all possible scenario sourcing decision makers need to create a win-win scenario. There are three layers to imbibe and inculcate a perfect competitive atmosphere.

a. Source development, measure & control
b. Open negotiation through digital platforms

a. Source development, measure & control.

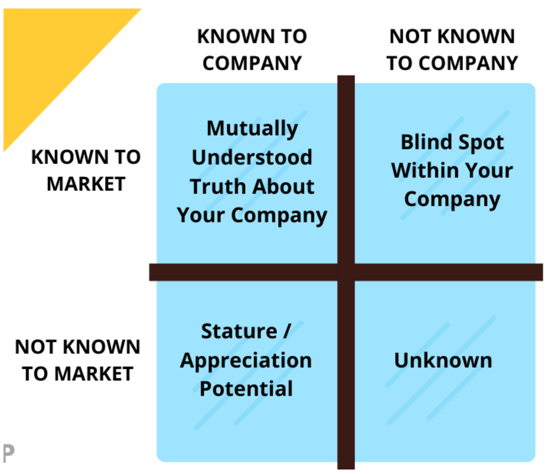
Concurrent ERP solutions provide generic onboarding, measurement and control process of sources. However effective SRM tool shall be effective to record, Monitor & control not only existing suppliers but also prospective sources. The system shall also facilitates communication with prospective and existing suppliers.

Modern e-procurement suits enable supplier development through target messaging, opportunity insights to the prospective sources. Systems enable self-registration & self-certification for onboarding.

AI based classifieds, Robotics process automation are instrumental in this development.

b. Open negotiation through digital platforms

Conventional offline negotiation has numerous disadvantages however the most critical disadvantage is he presence of blind spots amongst the negotiating parties:



(Fig 1: Johari window in Business. Ref 1)

Online negotiation platform connect multiple sources simultaneously and eliminate the blind spot amongst the seller as well as the buyers.

During online negotiation sellers knows what offer market is offering and make their individual position accordingly. [ref 2]

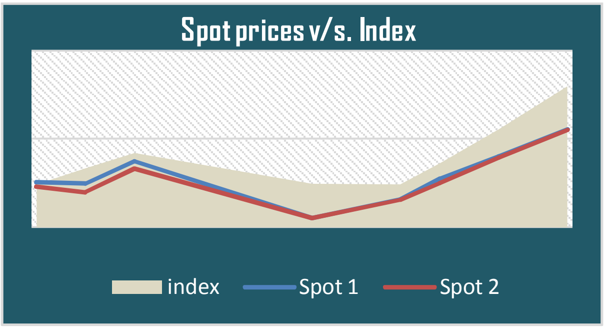
Industries use multiple online negotiation tools like e-market place, reverse auction, e-catalogue buy etc. Multiple stage e-bidding etc. There are numerous negotiation strategies available for each type of negotiation. Dutch, Yankee, No-ties, Japanese, SMRA to name a few.

However it's important to use the right strategy in e-negotiations. In selection of right negotiation strategy AI can have significant contribution. AI helps to scan participation data and with back tested algorithm it can reflect right negotiation strategy case to case basis.

CONCLUSION

Challenges are high while selecting the technology / tech process for spend management. However it's worth investing time before deploying tech-tools.

In Mjunction we are evolving with tech-adoption in sourcing raw materials for our clients. Following is a typical case study of tech-enabled sourcing process and derived value over time.



REFERENCES

[1] Value Prop: The-Johari-window-uncovering-the-blind-spots-in-business
[2] Margarita Janeska , Dejan Zdraveski,, Suzana Taleska: Trends and Challenges of Electronic Auctions as a New Business Model

Introduction of newly designed ladle heating system to reduce the arcing time for improved performance of refractory

Md. Sharique Aman[a], Shyam Jee, INP Gupta, I. Roy, M. K. Kujur

R & D Centre for Iron and Steel (RDCIS), Ranchi – 834002 (India)
Steel Authority of India Limited (SAIL)

[a] email: sharique.aman@sail.in

Abstract

In Steel Melting Shop steel is tapped from steelmaking furnace e.g BOF, EAF or EOF. Liquid steel is sent for further refining in a number of alternative processes known as ladle metallurgy. Ladle metallurgy is sometimes also called ladle refining or secondary steelmaking. In Secondary Steel making stringent operating parameters and strict control on chemistry and consistency is involved for production of high grades of steel.

In Secondary Steel making homogenization of chemical composition of liquid steel in the ladle, removal of carbon, oxygen, hydrogen and nitrogen, sulfur and undesirable nonmetallic elements is being done. For a certain grade of steel; these activities are governed by maintaining a particular range temperature of liquid steel. For maintaining the temperature range arcing is done. The arcing duration depends on the drop in steel temperature in ladle furnace. When the arcing duration increases due to drop in steel temperature, then it affects the refractory life of the ladle. The arcing duration was high in Steel Melting Shop of Durgapur Steel Plant which had detrimental effect on the performance of ladle refractory lining.

The new ladle heating system was designed and installed for arresting the steel temperature drop in the ladle furnace. A coke oven gas burner was designed, fabricated and installed. It was utilized for on line heating of steel ladles placed over the transfer car waiting for tapping. The introduction of ladle heating system has reduced the temperature drop in steel ladle. It reduced the requirement of arcing duration and directly contributed in the performance of improved ladle refractory.

Keywords - Steel Melting Shop; Secondary Steel making; ladle heating system

INTRODUCTION

Steel Melting Shop (SMS) of DSP is equipped with a ladle preheating bay for heating of ladles prior to tapping of steels into it. All these bays are provided with ladle heating burners using coke oven gas (COG) as fuel for pre-heating of ladles and air blower for supply of combustion air to the burner. For reducing the tapping temperature from the converters, it is necessary to provide sufficiently heated ladles with consistent ladle temperature. To achieve this, it is necessary so that all the ladles are heated to about 1200 °C before tapping. Green and repaired ladles of capacity 120 tons are heated to about 1200 °C in the existing 8 nos. of ladle heating stands. After preheating to a temperature of 1200 °C the ladles are placed on Steel Transfer Car (STC) for tapping. After placement of ladle on STC, the waiting time ranges from 15 - 30 minutes depending upon situations. This results in drop in ladle temperature. In case of circulation ladles, they are placed on the STC after fixing slide gate and making minor repairs. Most of the ladles are in semi-heated condition by the time they reach convertor for tapping with ladle temperature of about 750 – 900 °C. As a result, the steel temperature drop of more than

50 °C in ladle was found for about 60% heats. Hence, a heating facility for ladle on STC was introduced for giving service to one of the convertor in SMS of DSP to arrest further fall in ladle temperature as well as maintaining the ladle to its required temperature before tapping.

The temperature losses during tapping, holding time and teeming must be carefully controlled in the steel making process.
Magnesia carbon (MgO-C) bricks of different qualities are used in working lining. The carbon content MgO-C bricks in slag zone and metal zones are different.

LINING TEMPERATURE DROP

The holding time of molten steel in the ladle is decided on the basis of requirement for process and logistics of the shop. The waiting time for empty ladle before tapping is mainly determined by logistics of shop. The steel temperature drop and heat losses from ladle were determined by mathematical modelling and overall energy balance for the steel ladle [1].
Thermal stress is generated in refractory material as a result of temperature gradient generated during heating or cooling of ladle lining. The working lining of magnesia-carbon is exposed to bigger temperature change, mainly at tapping and immediately after tapping, when the temperature on magnesia brick surface is about 750 to 900°C and within few minutes after tapping, refractory bricks come into contact with hot molten slag and steel with a temperature of more than 1675 °C. These sudden changes in temperature may develop a crack in lining which is detrimental for ladle lining life. The two main probable causes of thermal crack development in working lining of ladle are [2]:

1) Cyclic heating and cooling of working lining in ladle during its operation.
2) Long waiting of ladle before tapping, about 30 minutes which causes large thermal shock for working lining at tapping.

The first cause is due to process requirement which may not be altered. The 2nd cause of waiting of ladle should be reduced as less as possible. But it may not be consistently less for all the heats because of logistics and ladle availability in shop.

During waiting the ladle is empty and being cooled from the inside and outside surfaces, losing energy to the surroundings by the mechanisms of radiation and convection [3]. The molten steel temperature drop is closely monitored and it is related to the ladle energy consumption. If it is above the specified tolerance limit during processing, electric energy is used through arcing to increase the steel temperature to meet the temperature suitable for casting. As a result, the energy consumption and the process time increases.

The waiting period for ladle before tapping influences the thermal state of ladle. Thus in turn affects the steel temperature in ladle.
Around 2.0 to 4.0 GJ of heat content is lost as per T. P Fredman [1], from steel ladle in one heat during the empty ladle waiting for the tapping.

LADLE HEATING SYSTEM

The high temperature ladle heating system consists of a high velocity burner along with ladle cover, combustion air blower, valves, piping's and instruments for measuring COG & air pressure.
There are two concentric tubes in high velocity burner for supply of COG and combustion air to the burner. Typical composition of COG available at DSP, Durgapur is CO_2 =3.0%, CO =8.6%, O_2 =0.6%, H_2 =58.1%, CH_4 =23.0%, C_2H_4 =2.0 & N_2 =4.5%. Firing capacity of the burner is 600 Nm^3/hr of COG at about 150 mmWC

pressure. The burner capacity is designed to reheat the circulation ladle with 2.5 GJ in 15 minutes to recover the heat loss during waiting period. The combustion air flow is designed for air flow with 10 percentages excess air required for the complete combustion of COG. Combustion air is supplied by the new installed combustion air blower of 3000 Nm3/hr capacity at 500 mmWC pressure.

A sketch of high velocity burner designed for this system is shown in Fig. 1. Nozzles are made of AISI: 310 grade stainless steel for longer life.

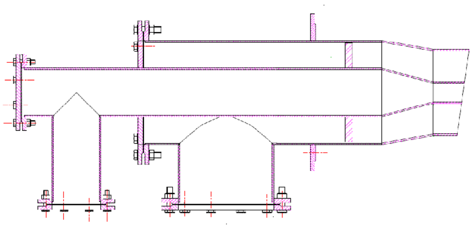


Figure-1: Sketch of the burner designed for the ladle heating system.

A ladle cover for 120 t capacity of ladle was designed and fabricated. Material of construction is mainly of AISI: 304 grade stainless steel. The ladle cover is provided with suitable ceramic fibre lining.

PERFORMANCE OF LADLE HEATING SYSTEM

The burner was lighted up using a pilot burner. Flame was visually examined for different air and gas flow rates. Flame thus generated was found to be about 3 meter long (Fig. 2) which is enough for the flame to reach bottom floor of the ladle during heating.

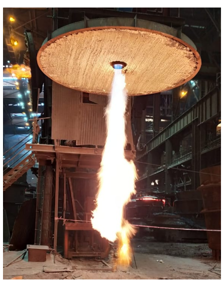


Figure-2: Flame of newly designed burner

CONCLUSION

High temperature ladle heating system is very efficient in heating the ladles in circulation to 1200 ^{o}C. It can heat up the circulation ladles to the temperature of 1200 ^{o}C within 20 minutes. The high velocity burner is capable of generating a stable flame with high thrust during low and high heat loads. At high heat load, flame length was about 3 metre long. It is expected that the enhanced ladle temperature obtained from the new ladle heating stand may result in lowering the steel temperature drop in ladle. Which in turn reduce the arcing time to increase the steel temperature for casting.

Lesser thermal shock and arcing time may contribute in enhanced refractory lining life resulting in more ladle availability.

ACKNOWLEDGEMENT

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REFERENCE

[1] Tom P. Fredman, J. Torrkulla, and H. Saxen´, "Two-Dimensional Dynamic Simulation of the Thermal State of Ladles," *Metallurgical and Materials Transactions B,* 324 -Volume 30B, April 199.

[2] J. Vlček, D. Jančar, J. Burda, M. Klárová, M. Velička, P. Machovčák, "Measurement the Thermal Profile of Steelmaking Ladle with Subsequent Evaluation the Reasons of Lining Damage", *Arch. Metall. Mater.*, Vol. 61 (2016), No 1, p. 279–282.

[3] M.F. Santos, M.H. Moreira, M.G.G. Campos, P.I.B.G.B. Pelissari, R.A. Angélico, E.Y. Sako, S. Sinnema, V.C. Pandolfelli, "Enhanced numerical tool to evaluate steel ladle thermal losses," *Ceramics International,* 44 (2018) 12831–12840.

Santosh Kumar
B Sunita Minz
Susanta Sarkar
Surendra Prasad
Nityananda Mondal
Rakesh Kumar Singh
Veda Prakash Upadhyaya
Editors

Proceeding of International Conference on Future of Refractories in Iron & Steel Industries

Future of Refractories in Iron & Steel Industries is a collection of technical papers enumerating the experimental & practical experiences of the manufacturers and consumer industries. It further specifies how Industry 4.0 has affected the refractory industry in monolithic, manufacturing and installation techniques, new developments in refractory formulations and use of nanotechnology in the field of refractories.

Among the topics covered is latest development in Monolithic Technology, installation techniques and manufacturing of refractories and techniques for energy savings. Emphasis has also been given on safety, environmental issues and recycling in addition to advanced technological solutions for quality & reliability as well as modeling & digitalization. Other topics include refractory characterization and testing, use of nano-technology in refractories for steel industry and use of artificial intelligence in refractory technology. The papers included are written by experienced industrial authors and experts from manufacturers, consultants and academia which will provide the reader an in-depth knowledge of the subject with insight on issues and challenges in the development and installation of these castables.

Every possible effort has been made to ensure that the information contained in this book provides a premier interdisciplinary platform for researchers, practitioners and scholars to understand the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Refractories during the current changing global scenario of Refractories and Raw materials.

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