AutoSOP 2015

International Conference on

Automotive Steel - Outlook & Perspective

December 11-12, 2015, Bokaro Steel City, Jharkhand, India

Organized by

IIM Metallurgy Materials Engineering

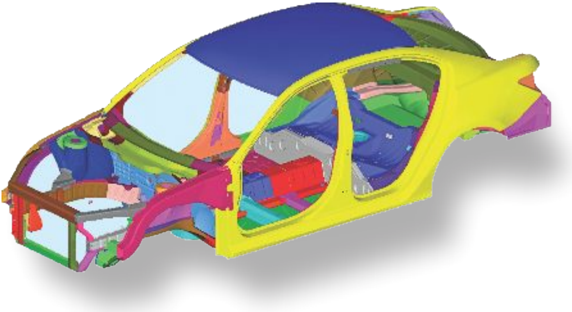
The Indian Institute of Metals
Bokaro Chapter

Bokaro Steel Plant
Steel Authority of India Limited

In association with

Research & Development Centre for Iron & Steel
Steel Authority of India Limited

Programme Schedule



CHIEF PATRON

Shri A Maitra
CEO,
Bokaro Steel Plant, SAIL

PATRONS

Shri S Dasgupta Executive Director (MM), BSL, SAIL	**Shri A Srivastava** Executive Director (P&A), BSL, SAIL
Shri Ajay Kumar Executive Director (F&A), BSL, SAIL	**Dr A M Kekre** Director I/c, M&HS, BSL, SAIL

ORGANISING COMMITTEE

Chairman **Shri A Bandyopadhyay** Executive Director (Works), BSL, SAIL	***Co-Chairman*** **Dr. B K Jha** Executive Director, RDCIS, SAIL

Organising Secretary

Shri D Chatterjee
General Manager (Quality), BSL, SAIL
Mob : +91-8986871031

PROGRAMME AT A GALANCE

Day 1 : December 11, 2015 (Friday)

1300-1420 Hrs	**Registration** *(HRD Centre)*
1430-1700 Hrs	**Inaugural Session** *(Main Auditorium, HRD Centre)*
1710-1800 Hrs	**Plenary Session** *(Main Auditorium, HRD Centre)*
1800-1830 Hrs	**High Tea** *(The Retreat, HRD Centre)*
2000-2300 Hrs	**Cultural Program & Dinner** *(Bokaro Club)*

Day 2 : December 12, 2015 (Saturday)

0900-1045 Hrs	**Technical Session I: Advances in High Strength Steel Processing** *(Banquet Hall, Bokaro Niwas)*
1045-1100 Hrs	**Tea** *(Banquet Hall, Bokaro Niwas)*
1100-1300 Hrs	**Technical Session II: Emerging Technologies for Production of Auto Steel** *(Banquet Hall, Bokaro Niwas)*
1300-1400 Hrs	**Lunch** *(Bokaro Niwas)*
1400-1545 Hrs	**Technical Session III: Quality of Auto Steel** *(Banquet Hall, Bokaro Niwas)*
1545-1600 Hrs	**Tea** *(Banquet Hall, Bokaro Niwas)*
1600-1700 Hrs	**Valedictory Session with Panel Discussion** *(Banquet Hall, Bokaro Niwas)*
1700-1730 Hrs	***High Tea*** *(Bokaro Niwas)*

Day 1 : December 11, 2015 (Friday)

INAUGURAL SESSION

Main Auditorium, HRD Centre, 1430-1700 Hrs

Programme Introduction

Welcome Address

Shri A Bandyopadhyay, Chairman, IIM Bokaro Chapter & ED(Works), BSL

Invocation Song

School Children

Lighting of lamp

Chief Guest with other dignitaries on dais

Address

Shri Anutosh Maitra, Chief Executive Officer, Bokaro Steel Plant, SAIL

Addresses by Guests of Honour

Inaugural Address by Chief Guest

Shri Sashi Shekhar Mohanty, Director (Technical) and Addl. Charge Director (Projects & Business Planning), SAIL & President, IIM

Release of Proceedings & Souvenir

Keynote Address: Automotive Steels - Some Future Trends

Prof. R K Ray, Visiting Professor, MN Dastur Centre of Materials Science & Engineering, IIEST Shibpur & Former Professor of Materials & Metallurgical Engineering, IIT Kanpur

Felicitation of Guests & Dignitaries

Vote of Thanks

Shri D Chatterjee, GM(Quality), BSL & Organising Secretary, AutoSOP 2015

National Anthem

PLENARY SESSION

Main Auditorium, HRD Centre, 1710-1800 Hrs

Presentation-1

Steel Making, Refining and Casting of Auto Steel

D Ravichandar & Sudhakar Asawale

JSW Salem Works, Salem

Presentation-2

Advanced High Strength Steels (AHSS) for Automobiles: A Review on Design Criteria

Sandip Ghosh Chowdhury, Biraj Sahoo, Avanish Chandan, Gaurav Bansal & Snehashis Tripathy

CSIR-National Metallurgical Laboratory, Jamshedpur

HIGH TEA

The Retreat, HRD Centre, 1800 – 1830 Hrs

Day 2 : December 12, 2015 (Saturday)

Technical Session - I

Banquet Hall, Bokaro Niwas, 0900-1045 Hrs

Advances in High Strength Steel Processing

Oral Paper - 1

Industry 4.0 & Industrial IoT for Indian Steel Industry

Mark Ferguson, PSI Metals Group, Germany

Oral Paper - 2

Development of Advance High Strength Material with Improved Yield Ratio and Excellent Bake Hardening Property

Rajan Kumar Singh, Madhawan Chandrawanshi, Sudharshan.R, Prashant Kumar Mehta, Devasish Mishra & Ashish Chandra
JSW Steel Ltd, Vijayanagar Works

Oral Paper - 3

Actual Shelf Life of BH Steel in Indian Context

Nemai Chandra Gorain & A N Bhagat, Tata Steel Limited, Jamshedpur

Oral Paper - 4

Improvement in Quality and Optimization of Skin Pass Rolling Load in Titanium Micro-alloyed Extra Deep Drawing Steel

Biswajit Sarkar & Ramen Datta, RDCIS, SAIL, Ranchi

Oral Paper - 5

Process Optimization for Microstructure Evolution of Annealed Cold Rolled Steel

B Sunita Minz, Santosh Kumar & Roselin Dodrae, BSL, SAIL, Bokaro

Oral Paper - 6

Strategies for Improved Wettability of Steels during Hot Dip Galvanizing

S K Mohapatra, RDCIS, SAIL, Ranchi

TEA

1045 – 1100 Hrs

Technical Session - II

Banquet Hall, Bokaro Niwas, 1100-1300 Hrs

Emerging Technologies for Production of Auto Steel

Oral Paper - 1

Advanced High Strength Steel (AHSS) Hot Rolled Coils Production for Automotive Industry

Matteo Remy Bulfone, Sanat Bhaumik & Santanu Rudra

Danieli Wean United, Italy & India

Oral Paper - 2

Strip Processing for Automotive Qualities

M Cottin, C Sasse & Rajesh Garg

SMS India

Oral Paper - 3

Cold Mill Complexes for Automotive Production

Djumlija Gerlinde & Dr. Finstermann Gerhard, Primetals Technologies

Oral Paper - 4

Danieli PLTCM in Yieu Phui Technometals, China for Production of High End CR Strips Automotive Application

Michele Turchetto, Sanat Bhaumik & Saugata Das

Danieli Wean United, Italy & India

Oral Paper - 5

Automated Roll Shop Project for New CRM of Bokaro Steel Plant

Pankaj Kumar & Vandana Tembulker, MECON Limited, Ranchi

Oral Paper - 6

Acid Regeneration Technology

Amit Kumar & Sudeep Chatterjee, International Steel Services Inc., India

LUNCH

1300 – 1400 Hrs

Technical Session - III

Banquet Hall, Bokaro Niwas, 1400-1545 Hrs

Quality of Auto Steel

Oral Paper - 1

Analyzing Failures through Customized Metallographic Techniques in Automotive Steel

Shomick Roy, Jitendra Mathur, Manashi Adhikary & Sandip Bhattacharya
Tata Steel Limited, Jamshedpur

Oral Paper - 2

Effect of Boron on Forming Behavior of Low Carbon Unalloyed Steel

Anjana Deva, Saikat K De, A Verma, B Mishra, S Roychowdhury, A K Bhakat, A Saxena & B K Jha, RDCIS, SAIL, Ranchi

Oral Paper - 3

Automotive Steel Production- Quality Improvement Initiatives in Continuous Casting

Anupkumar Nandakumar, Vesuvius India Limited, Kolkata

Oral Paper - 4

Innovations in Roll Cooling for Control of Flatness at Primary Cold Reduction

Santosh Chacko, Suresh Vasani & A K Ray, Lechler India, Thane

Oral Paper - 5

Improvement in Surface Quality for Auto Grade Steel

A K Roy, Bokaro Steel Plant, SAIL, Bokaro Steel City

Oral Paper - 6

Physical Metallurgy of Formable Sheet Steels

Dr. C D Singh, Steel Chair Professor, BIT Sindri

TEA

1545 – 1600 Hrs

Valedictory Session with Panel Discussion

Banquet Hall, Bokaro Niwas, 1600-1700 Hrs

Summary of AutoSOP 2015

Shri D Chatterjee, Organising Secretary, AutoSOP 2015

Opening Remarks

Shri A Bandyopadhyay, Chairman, IIM Bokaro Chapter & ED(Works), Bokaro Steel Plant

Panel Discussion: Challenges for Production of Automotive Steel in India

Panelists

- ***Dr. V. Ramaswamy***, Professor, Department of Metallurgical Engineering, PSG College of Technology, Coimbatore
- ***Dr. Sandip Bhattacharyya***, Chief of Scientific Services, Tata Steel India
- ***Shri Rajesh Garg***, Associate Vice President, SMS India Pvt. Ltd.

Concluding Remarks

Shri A Bandyopadhyay, Chairman, IIM Bokaro Chapter & ED(Works), Bokaro Steel Plant

Vote of thanks

Shri A. Dasgupta, Member, Organising Committee, AutoSOP 2015

HIGH TEA

The Retreat, HRD Centre, 1700 – 1730 Hrs

NOTES

ADVERTISERS

Advanced Mould Technology India Pvt. Ltd.	Minex Metallurgical Co. Ltd
Associated Plates & Vessels Pvt Ltd.	Parker
BEC	Premier Refractories of India Pvt. Ltd.
Bharat Comprehensive Packagers	Quaker Chemical India Pvt. Ltd.
Bokaro Steel Ltd	Quality Rubber Industry
Bosch Rexroth India Ltd	Ranchi Machine Tools Corporation
Casta Iron & Steel	RDCIS, SAIL
Chinar Engg	RHI India Pvt Ltd.
Cotmac Electronics Pvt. Ltd.	SAIL Safety Organisation
Danieli India	Salem Steel Plant
Gillanders Arbuthnot & Co. Ltd.	Samwha Refractory Group
GR Enterprises	SARVESH Refractories Ltd
Hardcastle Petrofer Private Ltd.	Schmiede and Maschinen (Pvt.) Ltd
Hi-tech Chemicals (P) Ltd	Shailja Enterprises
Industrial Pumps & Motors Agencies	Signode
International Steel Services Inc.	SMS India
Jharkhand Grind Chem Pvt Ltd	Sunag Engineering Pvt. Ltd.
M.D. Esthappan	Taylor Winfield Technologies, Inc.
MECON Limited	Tenova S.p.A.
Metal Traders & Processing Co.	Utkal Automobiles Pvt Ltd
Metalock Maco Engineering India Pvt. Ltd.	Vesuvius
	Yuken India Limited

SPONSORS

Platinum Sponsors

DANIELI

INTERNATIONAL STEEL SERVICES,INC.

Gold Sponsors

RHI

SIGNODE
Signode India Limited

Silver Sponsors

strengthening growth
BEC
BHILAI ENGINEERING CORPORATION LIMITED

三華集團
SAMWHA GROUP

SARVESH Refractories Limited

tenova

Co-sponsor

VESUVIUS

Media Partner

IRON & STEEL REVIEW

Advanced High Strength Steels (AHSS) for Automobiles: A Review on Design Criteria

Sandip Ghosh Chowdhury, Biraj Sahoo, Avanish Chandan,
Gaurav Bansal & Snehashis Tripathy
CSIR-National Metallurgical Laboratory, Jamshedpur, 831007
Email: sgc@nmlindia.org

Higher fuel efficiency, lower CO_2 emissions and increased safety of passenger lead to the development of automotive grade steel. Fuel efficiency is related to the weight of the components; whereas, crash resistance is largely achieved by increasing the energy absorbing capacity of the steel. This led to the development of advanced high strength steels (AHSS) with optimized strength and formability.

Highly formable grades generally are ultra-low carbon steel, Interstitial Free (IF) steel wherein the solute carbon is fully or partially stabilized by Ti or Nb. Among AHSS the most common is the Dual Phase (DP) steels which consist of Ferrite-Martensite Structure. DP steels typically have high ultimate tensile strength (UTS) (enabled by the martensite) combined with low initial yielding stress (enabled by the ferrite). Another grade of steels is the Transformation-induced plasticity (TRIP) steels which consist of ferrite-bainite microstructure with some amount of retained austenite. They have higher strength and elongation than DP Steels. Other steels being used in automotive parts include multiphase steels having complex microstructure consisting of various phase constituent and fully martensitic steel having high strengths. In the present paper, the development of various AHSS will be discussed along with their processing schedule as well structure-texture-property correlation.

Keywords: AHSS, IF Steel. DP Steel, TRIP/TWIP Steel, Texture, Formability

Automotive Steels - Some Future Trends

R. K. Ray
Visiting Professor, MN Dastur Centre of Materials Science & Engineering, IIEST Shibpur
Email: rkray@iitk.ac.in

In order to effect better fuel economy and to reduce greenhouse gas emissions, the requirement to decrease the weight of automobiles has become more stringent in recent years. In order to meet these demands from the auto manufacturers, the traditional focus of material development has been mainly in the areas of high-strength and highly formable steels. This approach relies on the down-gauging of advanced high -strength steels, utilizing their exceptionally high strength levels. However, there is a basic limitation in this approach in the sense that to keep the stiffness at an acceptable level, a steel cannot just be down-gauged to any extent. Rather, it is quite possible to reduce the weight of an automobile directly by developing low density steels, which will allow the use of a thicker gauge.

The stiffness of a sheet is influenced by both the density and the elastic or Young's modulus. Just as a lower density would allow the use of a thicker gauge to increase the stiffness, a higher elastic modulus, on the other hand, will directly increase the stiffness. Both these approaches of lowering the density and enhancing the elastic modulus of steels are relatively new fields in research and are, therefore, less focused areas in the literature.

The present lecture will primarily dwell on these new and exciting areas of research, which may yield substantially better materials for the automotive industry. In addition, mention will be made of some unconventional and out of the box procedures which can be profitably utilized by the industry as a way forward for future development.

Keywords: Low Density Steels, Young's Modulus, Stiffness

Physical Metallurgy of Formable Sheet Steels

C D Singh
Department of Metallurgical Engineering, B.I.T. Sindri, Dhanbad-828123
Email: cdsingh48@yahoo.com

Control of texture and hence of formability, particularly deep drawability, is one of the important goals when processing formable steels (i.e. low carbon and IF steel sheets). The texture generated during cold rolling depends also on steel chemistry and hot rolling parameters as well as on hot band grain size. Further, the cold rolled generated texture is modified which takes place by recrystallisation and grain growth during annealing which is the main task.

An overview of the results concerning recrystallization texture in formable sheet steels is presented. These results point, among other things, to the importance of a favourable texture in which a large proportion of grains are oriented with {111} planes parallel to the sheet plane. Three important cases of industrial practice i.e.(i) batch annealing of Al – killed steels,(ii) continuous annealing of low carbon steels and (iii) processing of IF steels, are taken up for presentation.

Additionally, results of texture evolved in industrially produced low carbon Al-killed steel sheets of different thickness are presented. To characterise the forming behaviour of these sheets, studies about the rm values, yield locus and forming limit diagrams have carried out and presented. The physical metallurgy of the industrial practices is discussed, and a summary of the most important conditions for optimum texture and formability is presented.

Keywords: Texture, Cold Rolling, Hot Rolling, Batch Annealing, Continuous Annealing, Low Carbon Steels, IF Steels, Yield Locus, Average R-Value, Forming Limit Diagram

Development of Advance High Strength Material with Improved Yield Ratio and Excellent Bake Hardening Property

Rajan Kumar Singh, Madhawan Chandrawanshi, Sudharshan. R,
Prashant Kumar Mehta & Devasish Mishra
JSW Steel Ltd, Vijayanagar Works. Toranagallu, Dist: Bellary, Karnataka-583275, India
Email: rajan.singh@jsw.in

Effect of various annealing parameters on mechanical property and microstructure for DP590, 780 and 980 were investigated through Gleeble thermal simulation and Continuous Annealing Line (CAL) trials. Cold rolled full hard samples of Dual Phase (DP) grades were initially simulated in Gleeble for different soaking section, rapid cooling and over-aging section temperatures. Mechanical properties along with microstructure were investigated for the same. Identical annealing cycles were performed at continuous annealing line and results were compared with the Gleeble simulation results. Significant improvement in tensile strength with decrease in rapid cooling were observed in simulated samples and in CAL trial coils, whereas decrease in tensile strength were observed due to decomposition of martensite at higher rapid cooling as well as over-aging temperatures. There is significant increase in yield strength observed after forming, baking and painting of annealed samples. YS to TS ratio of DP steel is observed less than 0.6 as compared to 0.8 in HSLA grades, indicating DP steels are more formable than HSLA grades at a similar strength level. It is also concluded that increasing annealing temperature beyond Ac_3 *does not increase the martensite fraction as well as tensile strength in continuous annealed steel.*

Keywords: Dual Phase Steel, Cold Rolled Dual Phase Steel, Continuous Annealing, Gleeble Simulation

INTRODUCTION

Automotive industries are looking for lightweight materials to increase the fuel efficiency without compromising the safety and luxury. Light materials like aluminium, magnesium, plastic and composites are also being used as steel alternatives. Thinner gauge automobile designs for weight reduction leads to development of advanced high strength steels. Automotive structural parts required a good combination of strength and ductility. Advanced high strength steels offer excellent combinations of strength and formability. DP (Dual phase) steel is member of Advanced high strength steel family along with TRIP (Transformation Induced Plasticity), CP (complex Phase), Mart (Martensitic Steel) etc. Hard martensite phase and soft ferrite phase of DP steel results in an excellent high strength and formability combination. High strain harden ability of DP steel provides its high energy absorption capacity. As these grades also exhibit bake hardening, it can be used as effectively design parts for optimum performance. Combining these properties with an excellent fatigue strength make these grades of steel a remarkable candidate for structural parts in vehicles such as longitudinal beams, cross members and reinforcements. The dual phase steel can be used for roll forming and stamping of door-intrusion beams, bumper-reinforcement beams, and various seating components, such as tracks, pillars, risers and towers.

After cold rolling, materials are annealed to increase the formability by relieving the stress generated during cold rolling. In continuous annealing, coil strips are uncoiled at the entry and welded together, welded strip subjected to a sequence of furnace sections as a continuous strip, being heated at different furnace sections over a period of several minutes then cooled and fed to skin pass mill directly. All furnace sections have significant effect in microstructure. In preheating section, recovery of grains of cold rolled full hard sheet occurs. Carbides dissolution occurs in soaking section where the temperature is in inter-critical region, and nucleation and growth of austenite take place around the carbides. After soaking, sheet is slowly cooled to below Ac_1 temperature in slow cooling section to decrease the austenite fraction. High speed cooling at rapid cooling section results in microstructure, super saturated with carbon, which accelerates carbides precipitation during over-aging at over-aging section.

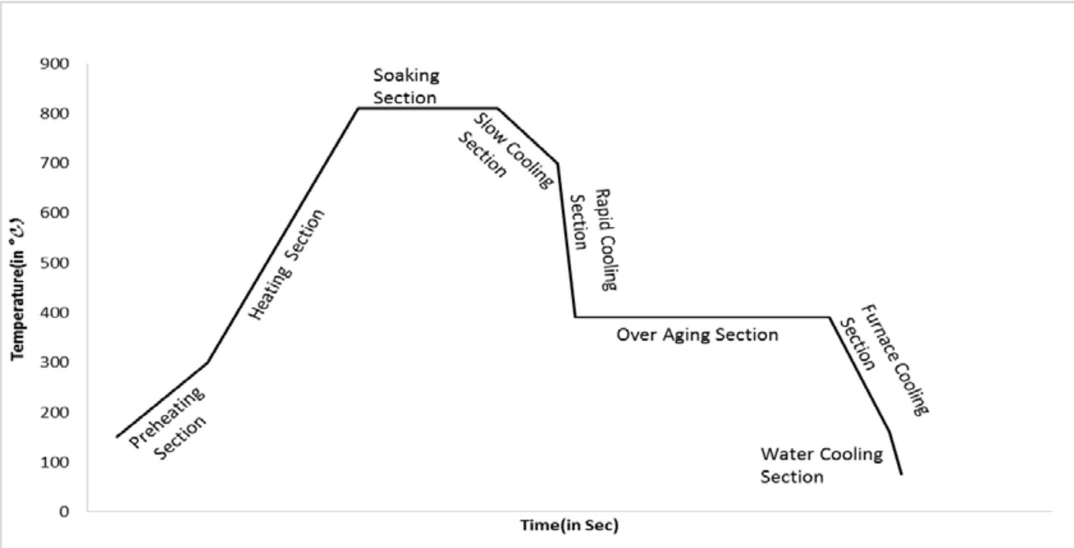


Fig 1 Typical annealing cycle of Continuous annealing line

EXPERIMENTAL

An industrial heat was produced using a BOF converter followed by RH degasser and subsequently casted in a continuous caster. Slabs were reheated to maximum 1240°C and then hot rolled in two reversible roughing mills and 7-stand finishing mill. The finishing mill exit temperature is kept less than 920°C with coiling at less than 650°C. Hot rolled coils are consequently processed through pickling coupled with tandem cold rolling mill to remove the oxide surface present in the surface and to provide cold reduction from 45 % to 65%. Following pickling and cold rolling to desired thickness, cold rolled steel strip are processed through continuous annealing line, where electrolytic cleaning removes rolling emulsion present on the surface. Cold rolled full hard samples were collected at this stage to perform simulation in Gleeble. Cleaned strip surface passes through the preheating and the heating section where the strip is heated at the rate of 10°C /sec or less from preheating section to soaking section temperature maintained at Ae_3-70°C to Ae_3-20°C for 100 seconds. After soaking section, steel strip passes through slow cooling section at cooling rate of less than 7°C/sec. Slow cooling section temperature was maintained at more than 650 °C. Following slow cooling section, annealed strip sheet was rapid cooled at more than 25 °C/sec to rapid cooling section temperature of Ms-140°C to Ms-20°C. After rapid cooling section, annealed strip was over aged keeping the over aging section temperature more than 300°C. After over aging, Skin-pass elongation (during temper rolling) of 0.8 % or more was done to avoid yield point elongation.

Cold rolled full hard samples were initially simulated in Gleeble 3800 – Thermo Mechanical Simulator for different soaking section and rapid cooling temperatures. Identical annealing cycles were performed at Gleeble simulation and results were compared with the continuous annealing line results. Surface quality tests, such as Phosphatability test, were also done on the samples as surface properties are critical for automotive applications. Mechanical properties along with microstructure were investigated for the continuous annealed and Gleeble simulated samples. Samples were also examined under scanning electron microscopy. Fatigue test was conducted on the samples. Similar studies are conducted for DP780 and DP980 but this paper discusses results of DP600 only.

Table 1 Typical chemical composition of DP600, DP780 and DP980

Steel Grade	**C**	**Mn**	**Si**	**Others**
DP600	0.15 Max	2 max	0.5max	Cr, Nb, Ti
DP780	0.2 Max	2.5 max	0.5max	Cr, Nb, Ti
DP980	0.2 Max	3 max	0.5max	Cr, Nb, Ti

RESULTS & DISCUSSIONS

The microstructure of hot rolled steel consists of ferrite and pearlite phases in banded structure. Due to high manganese content, the banded structure is formed. As manganese decreases the Ac_1 temperature, manganese rich portions will transform to austenite prior to low manganese portions. Microstructure of full hard DP600 after cold rolling contains elongated and broken pearlites.

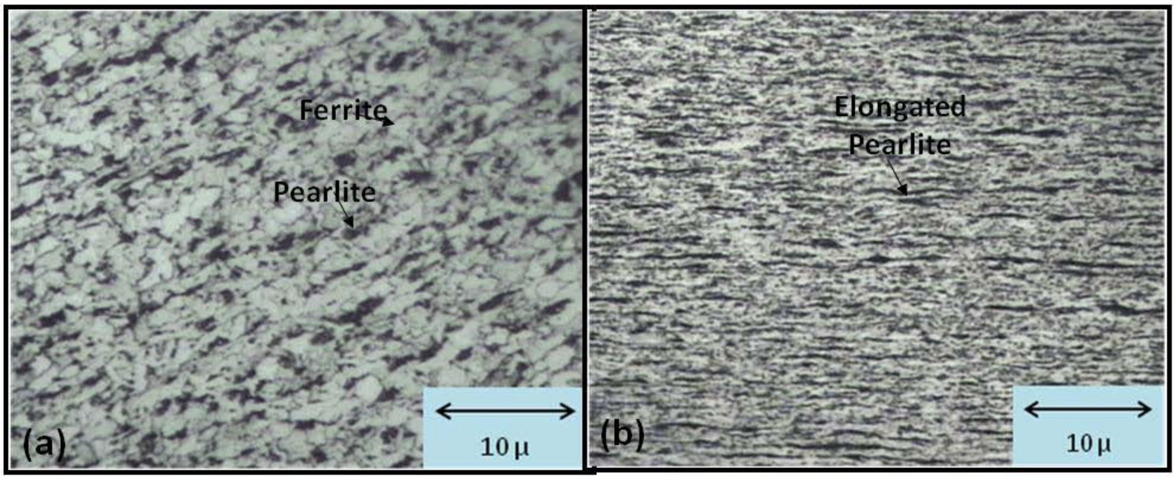


Fig 2 Microstructure of DP 600 (a) after hot rolling (b) after cold rolling

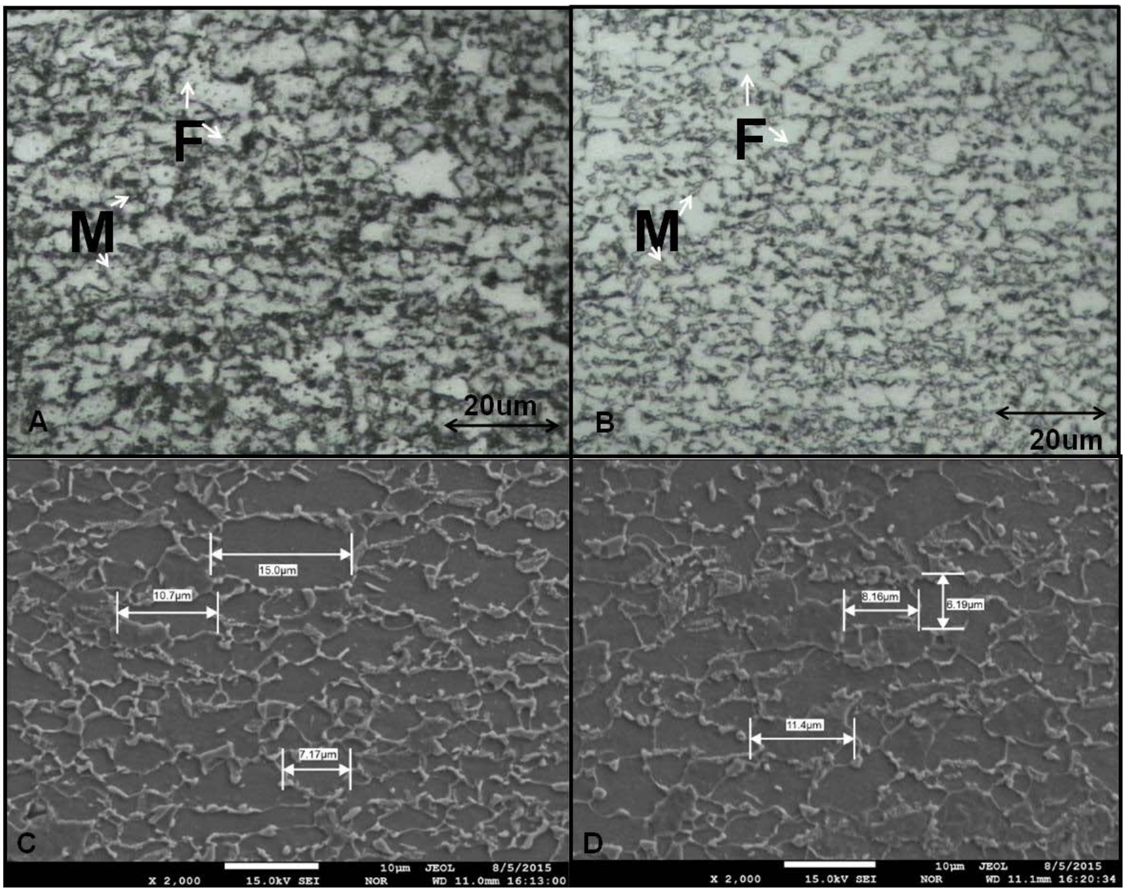


Fig 3 Shows DP600 (A) Microstructure of continuously annealed sample (B) Microstructure of Gleeble simulated sample (C) SEM of continuously annealed sample (D) SEM of Gleeble simulated sample

Microstructure of continuously annealed DP600 contains more than 20% martensite and other secondary phase, such as bainite and retained austenite, are distributed over soft polygonal ferrite matrix. Ferrite phase have average grain size less than 8µm. Phase fractions and grain size were calculated by using ImageJ software. Gleeble simulation microstructure reveals somewhat higher amount (~22%) of second phase fraction (Martensite + Bainite) as compared to Continuous annealing line.

Table 2 Typical Mechanical Properties of DP600, DP780 and DP980

Steel Grade	YS (MPa)	UTS (MPa)	El%	BH(MPa)	YS/TS ratio
DP600	398	660	28	>40	0.60
DP780	476	838	21	>40	0.57
DP980	600	1072	15.3	>40	0.56

Observed bake hardening values are more than 40MPa. Bake hardening property in DP steel is greater than HSLA grades. Improved bake hardening and forming property of dual phase steel allows designer to decrease the thickness of the component with similar load bearing capacity that help in reducing the overall weight of the vehicle which improves the fuel efficiency. This enhanced bake hardening property can be accounted to the available nitrogen and carbon in ferrite phase. Significant YS to TS ratio of DP steel is observed less than 0.6 as compared to 0.8 in HSLA grades, indicating DP steels are more formable than HSLA grades at a similar strength level. Also low yield ratio make DP steel suitable for high energy absorption application in automobiles. High bake hardening and low yield ratio makes dual phase steel a prime choice for automotive inner panels as it is easy to form in desired shape because of it high formability and there is significantly improvement in strength after painting and baking.

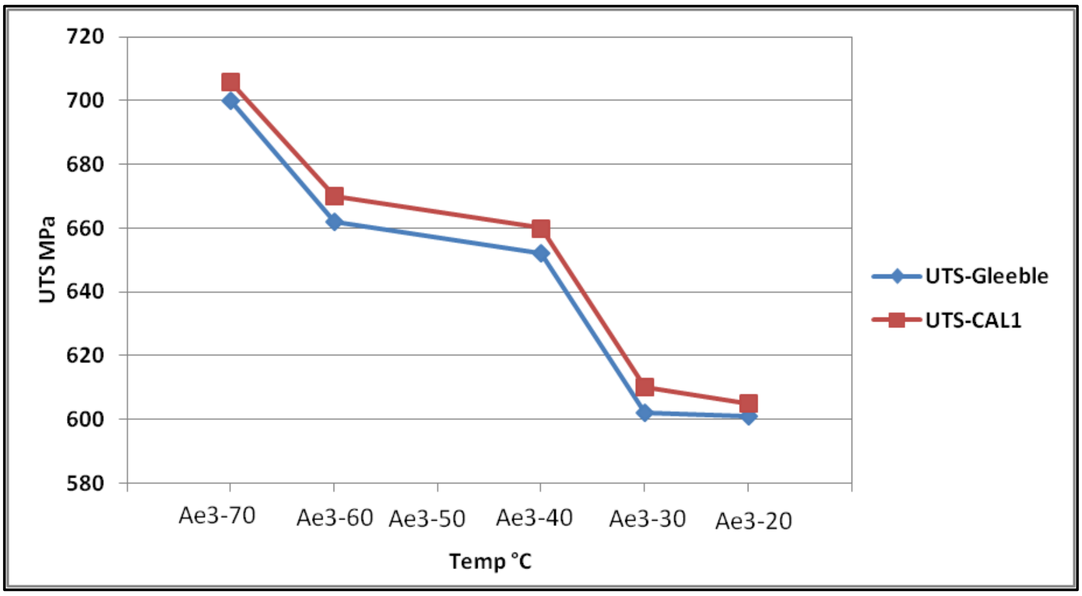


Fig 4 CAL soaking temperature vs. UTS value

Tensile strength decreases with increasing soaking section temperature that can be explained by decrease in martensite fraction with soaking temperature. As soaking temperature increases, austenite fraction will increase but carbon % in austenite will decrease that decreases the hardenability of steel with formation of epitaxial ferrite during - cooling resulting in decrease in volume fraction of martensite[1]. Before get transformed to martensite, ferrite fraction will increase due to transformation of austenite in epitaxial ferrite. Increasing annealing temperature beyond Ae_3-30˚C does not increases the martensite fraction as well as tensile strength, attributing to the fact that increase in volume fraction of austenite is nearly equal to the formation of epitaxial ferrite such that transformed martensite remains same. Slightly lower property in spite of little higher secondary phase fraction of simulated sample can be accounted for secondary phase distribution and morphology and also for the phase fraction of martensite, bainite and retained austenite of simulated and continuously annealed samples.

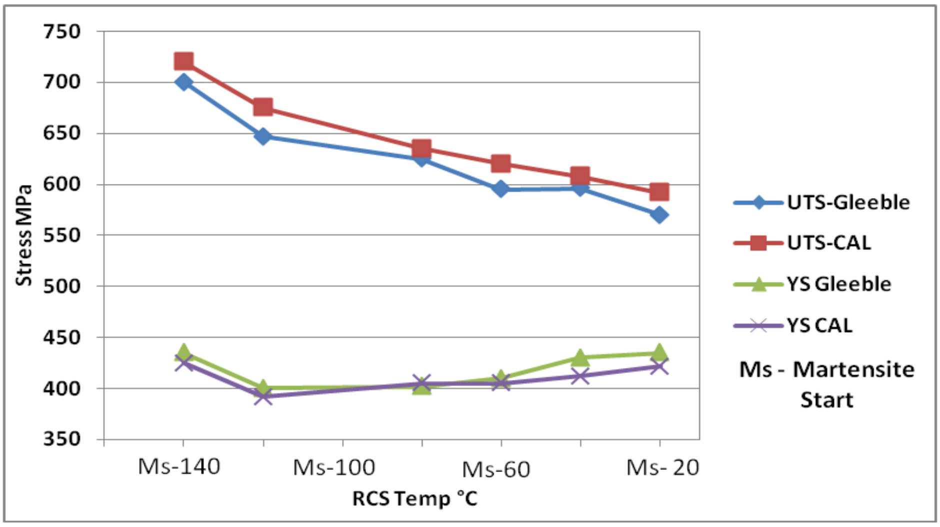


Fig 5 Mechanical property correlation between CAL and Gleeble simulated DP600 steel at various RCS temperatures

Tensile strength increases with increasing the cooling rate, as increasing rapid cooling rate will result in higher amount of secondary phases such as martensite and bainite. Significant improvement in tensile strength with decrease in rapid cooling temperature was observed in simulated samples and in CAL trial coils, whereas decrease in tensile strength was observed due to decomposition of martensite at higher rapid cooling as well as overaging temperatures. There is not much effect of rapid cooling temperature on yield strength as yield stress is mainly provided by the ferrite phase. Nb is added for grain refinement of ferrite, increasing the yield strength. Tensile properties are very much depended upon the secondary phase martensite and bainite as dislocation movement is hindered by hard martensite phase.

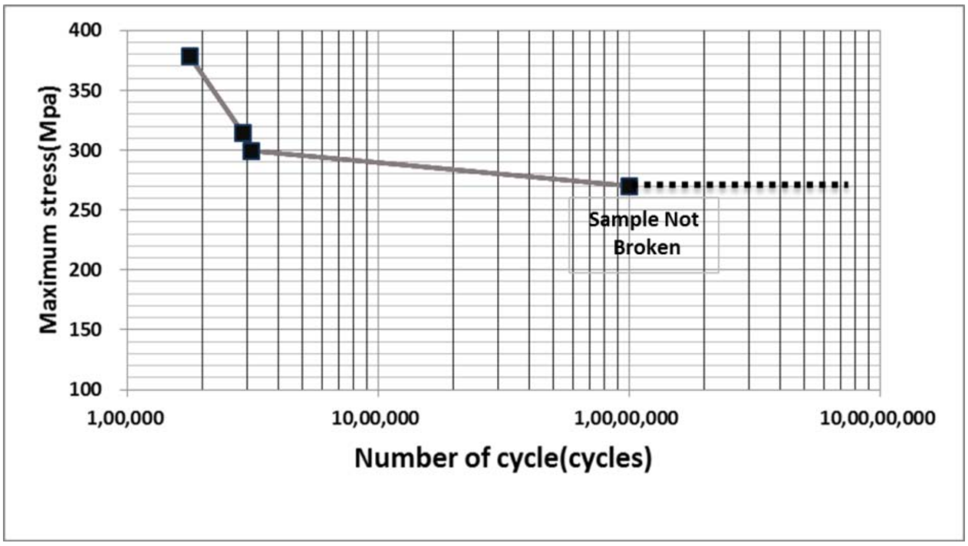


Fig 6 S-N Curve for Continuously annealed DP600

Dual phase steel shows higher fatigue strength due to its high mechanical strength. Due to martensite, higher yield and tensile properties of DP steel decreases the fatigue crack growth rate[2]. Endurance limit of continuously annealed DP600 sample is found to be 270MPa. In DP steels, crack deflection occurs at ferrite, ferrite/martensite interfaces and ferrite grain boundaries that facilitate crack closure[2].

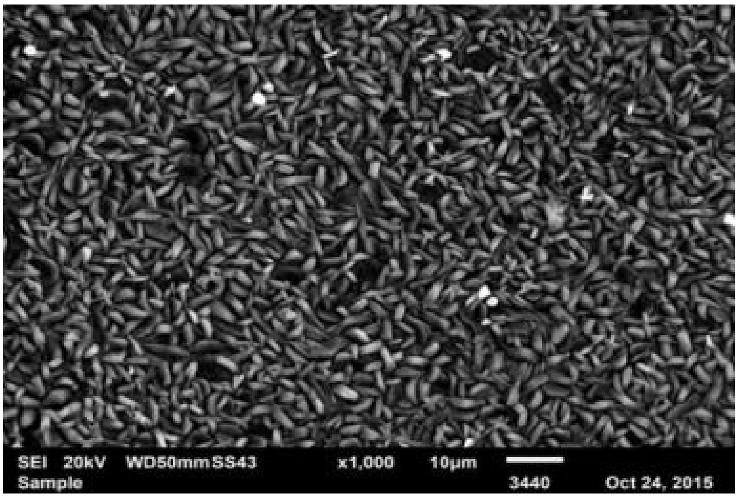


Fig 7 SEM Micrograph Phosphate crystals after Phosphatability test of continuously annealed DP600

For excellent Phosphatability, larger quantity of small phosphate crystal homogeneously distributed on the surface is the most favourable condition. Mn and Si, the fundamental alloying elements for steel, are vulnerable to oxidation and easily form their oxides on the steel surface, as a consequence Phosphatability of steel suffers. Continuously annealed sample of DP600 with Mn maximum 2.5 wt. % shows excellent Phosphatability with small phosphate crystal size of 3-4µm and coating weight of 2.2g/m^2.

CONCLUSION

Properties of DP steels from Continuous annealing are comparable to that of Gleeble simulation. Microstructure of Gleeble simulated DP steels reveals somewhat higher amount of secondary phase fraction (Martensite + Bainite) as compared with that of Continuous annealed DP steels. Reducing the Rapid cooling section temperature or increasing the cooling rate resulted in higher UTS values for all DP steel grades. Increasing annealing temperature beyond Ae_3-30˚C does not increase the martensite fraction as well as tensile strength. There is significant increase in yield strength observed after forming, baking and painting of annealed samples. DP steels are more formable than HSLA grades at a similar strength level. DP steels have very good fatigue strength due to very high tensile strength. Also DP steel shows excellent Phosphatability with small crystal size and less coating weight.

REFERENCES

1) Guo-hui Zhu, Xue-hui Zhang, Wei-min Mao, Development in high-grade dual phase steels with low C and Si design, Frontiers of Materials Science in China, Vol3(2009), pp 442-446

2) Irwan Herman Onn, Norhayati Ahmad, Mohd Nasir Tamin, Fatigue Characteristics of Dual Phase Steel Sheets, 9th International Conference on Fracture & Strength of Solids, June 9-13, 2013

3) R.O.Rocha, T.M.F.Meloa, E.V.Pereloma, D.B.Santos,Microstructural evolution at the initial stages of continuous annealing of cold rolled dual-phase steel,Materials Science and Engineering A 391 (2005) 296–304

4) Kumkum Banerjee, Role of Base Metal Microstructure on Tensile Properties and Weldability of Simulated Continuously Annealed Advanced High Strength Steels, International Journal of Metallurgical Engineering 2013, 2(1): 100-110

5) S.K.Akay, M.Yazici, A.Bayram, A.Avinc,Fatigue life behaviour of the dual-phase low carbon steel sheets,journal of materials processing technology 209(2009)3358–3365

6) G.Avramovic-Cingara, Y.Ososkov, M.K.Jain, D.S.Wilkinson,Effect of martensite distribution on damage behaviour in DP600 dual phase steels, Materials Science and Engineering A516 (2009) 7–16

7) Wolfgang Bleck, Cold-rolled high-strength sheet steels for auto applications, JOM Jul 1996, 48, 7

Industry 4.0 and Industrial IoT for Indian Automotive Steel

Mark Ferguson
PSI Broner Metals, UK & Germany
Email: *mark.ferguson@bronermetals.com*

Industry 4.0 and Internet of Things (IoT) are two much talked about concepts in the digital space of manufacturing. The Industry 4.0 denotes the fourth industrial revolution and it is a collective term embracing a number of contemporary automation, data exchange and manufacturing technologies. It is a concept of making smart factory by combining real and virtual worlds in manufacturing. On the other hand the IoT can be defined as interplay for software, telecom and electronic hardware industry, which promises to offer tremendous opportunities for many industries. Though both the concepts appear to be highly promising for the manufacturing industries, there are various questions to be answered before implementing them in Indian industries in general and automotive steel industry in particular.

India has amazing resources – people, geography, education, natural resources and a well placed government policy. The world is watching growth trajectory of India. Now it's the turn of Steel Industry to prove it! The present paper finds out what's driving Industry 4.0 thinking, how it affects India, and how it helps Indian automotive steel manufacturing companies compete against other developed countries in this tough global market. The paper also examines readiness of the Indian production plants and supply chain for adoption of these concepts and gauges their need, how will it help, what will it cost, what are the benefits, etc. It is found that these new concepts are helpful in improving customer service, reducing costs, improving efficiency, and driving-up margins.

Keywords: Industry 4.0, Internet of Things (IoT), Indian Steel Industry

Actual Shelf Life of BH Steel in Indian Context

Nemai Chandra Gorain & AN Bhagat
Tata Steel Limited, Jamshedpur, Jharkhand-831001, India
Email: nemai@tatasteel.com

Production of bake hardenable (BH) steel requires advanced skills in steel making and downstream processing. It needs precise control of steel chemistry as well as the process parameters to retain an appropriate amount of interstitial solutes carbon, responsible for BH value of the steel as well as its shelf life. Internationally, shelf life is accepted as three month at room temperature (~30° C). In India, consuming the steel within this period is difficult due to geographic distance between steel-plants and automakers. Also, temperature faced by the material during transportation and stocking is generally higher than room temperature in India. In this present work actual shelf life of BH samples was evaluated at 40° C in a constant temperature oil bath. Samples were taken out from the bath at different interval to find out the extent of aging. The amount of solute carbon and nitrogen were also estimated by internal friction measurement method. Results from these experiments suggest that, lower amount of solute elements are desirable in BH steel to achieve the shelf life of three month at 10° C above room temperature. Further work needs to be done to improve the BH value with sufficient shelf life in the Indian context.

Keywords: Bake Hardenable, Shelf Life, Internal Friction

INTRODUCTION

Automotive outer panel needs combination of formability and dent resistance property. Generally formability of steel decreased with the increase in yield strength, which gives a proportional dent resistant property. Again, to reduce emission by lowering the vehicle weight i.e. using thinner panels of higher strength, dent resistivity and formability both are difficult to achieve unless we have bake hardening steel. Cold rolled annealed and temper-rolled bake hardening steel is a well-established material for automotive panels due to its increase in strengthening effect during pain baking process. Various grades of BH steel are available commercially, classified as per the minimum yield strength like BH-160, BH-180, BH-220, BH-260 etc. A schematic diagram (Fig 1) shows increase in yield strength during work hardening and bake hardening process.

Bake hardening property can be increased by increasing the presence of solute carbon in steel. But high amount of solute carbon in steel is prone to strain ageing at ambient temperature causing stretcher strain marks (Fig 2) during deformation. Therefore, an optimum amount of solute is desirable in BH steel. The steel should possess sufficient shelf life for transportation and storage time before forming it to its final shape. Hence, there is a need to predict the shelf life of the steel after temper rolling. It is generally performed by evaluating aging index (rise in flow stress after accelerated aging test at 100o C after 7.5-10% strain). This test does not predict the shelf life well. The method presented by Hundy[1] for aging simulation using Cottrell-Bilby model[2] is not suits well for predicting ambient aging behaviour for temper rolled material. Subsequently the Hundy's method has been modified by Bhagat[3] for the prediction of shelf life applicable in industrial practice for room temperature shelf life. Due to wide variation in temperature during transportation and warehousing further study is required to predict the shelf life of the BH steel when kept above the room temperature (40-45°C). For that purpose experiments were conducted to find out the actual shelf life of a trial BH steel sample, keeping it in a constant temperature oil bath for a prolonged period. The amounts of interstitial solutes were estimated by internal friction measurement to corroborate the obtained shelf life of the samples.

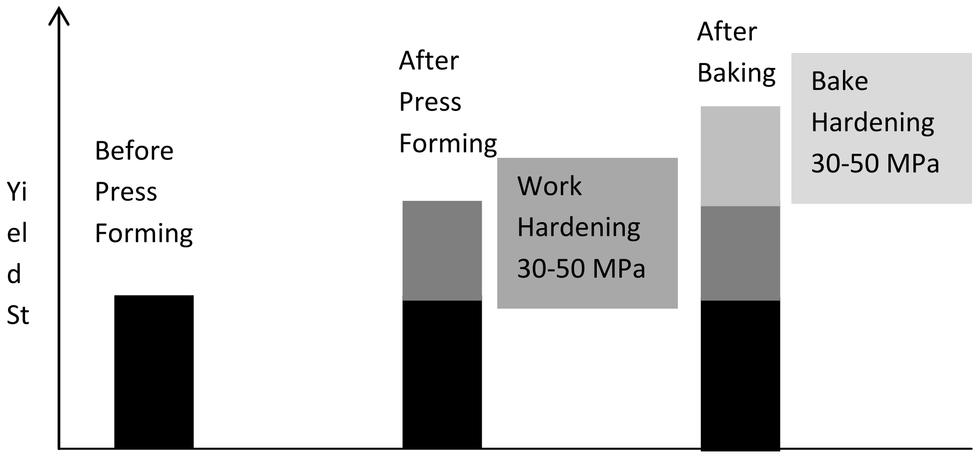


Fig 1 Schematic diagram of BH process

Fig 2 Ludder Band marks on the tensile sample

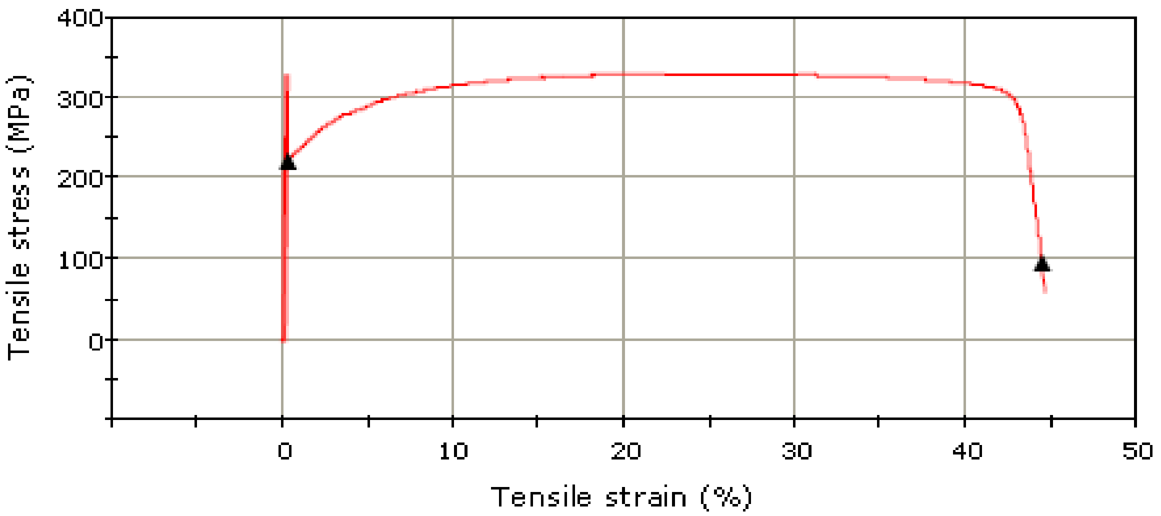
EXPERIMENTAL

The steel sheet sample for the experiment were produced trough RH, continuous casting, hot rolling, cold rolling, batch annealing (BA) and temper-rolling (~ 1.3% deformation). In the present sample a certain amount of carbon was kept in solution till its final sheet product. Therefore, ultra low carbon (C ~0.002%) steel without scavenging elements was rolled for BA route. The approximate chemistry of the sample is given in Table1.

Table 1 Approximate weight percent of the chemical composition of the sample

C	Mn	P	S	Al	N
0.002	0.300	0.040	0.005	0.050	0.001

Dumbbell shape longitudinal tensile sample of gauge length 50 mm and with 25 mm were prepared from the sheet sample of thickness 0.63 mm for tensile properties. The tensile properties are given in Fig 3. Tensile specimens were pre-strained to 2% and then heated for 20 min at 170°C (as per conventional paint baking process) for determination of bake hardening (BH) strength. BH strength is the difference between lower yield stresses measured from these aged specimens and the flow stress prior to deformation.



Yield Stress (Offset 0.2 %, MPa)	Maximum Load (MPa)	Elongation (%)
219	330	44.5

Fig 3 Tensile property of the sample before aging

To study the aging behaviour above room temperature, the samples were aged for various periods (up to three months) in a specially designed oil bath furnace, which was maintained at a constant temperature of 40 (+ 0.1) °C. The yield point elongations (YPE) were measured at each 15 days interval. The schematic diagram of the oil bath is shown in Fig 4 and its pictorial view is given in Fig 5. The comparison of YPE measured by tensile testing is show in Fig 6.

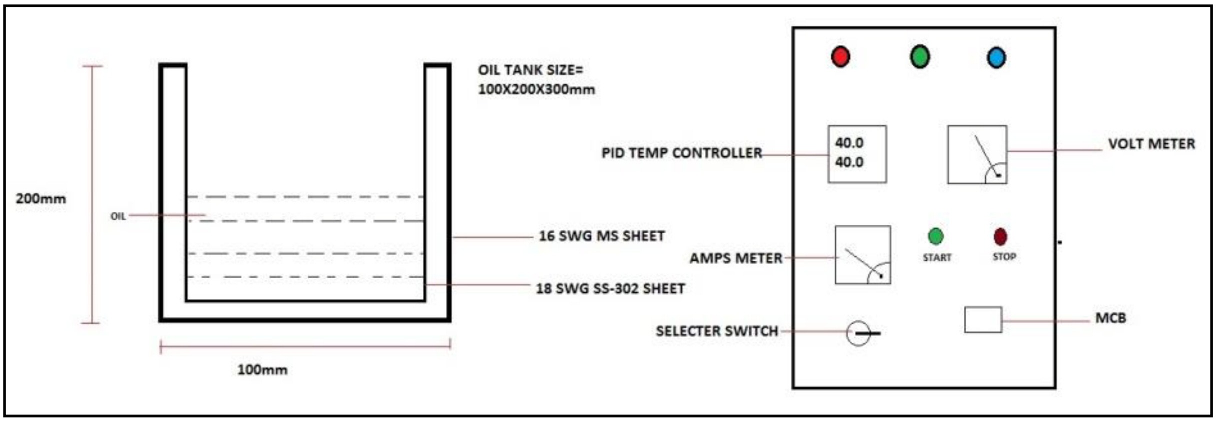


Fig 4 Diagram of the constant temperature oil bath

Fig 5 Pictorial view of the constant temperature oil bath

To compare the accelerated aging behaviour of the temper rolled and 2% tensile deformed samples were heated at 100°C for various periods (at 30 min interval) and measured the yield point elongation. The plot of these data is given in Fig 7. The YPE value after 60 min is 0.14% which is equivalent to the shelf life of 2 to 3 months as per the industrial practice.

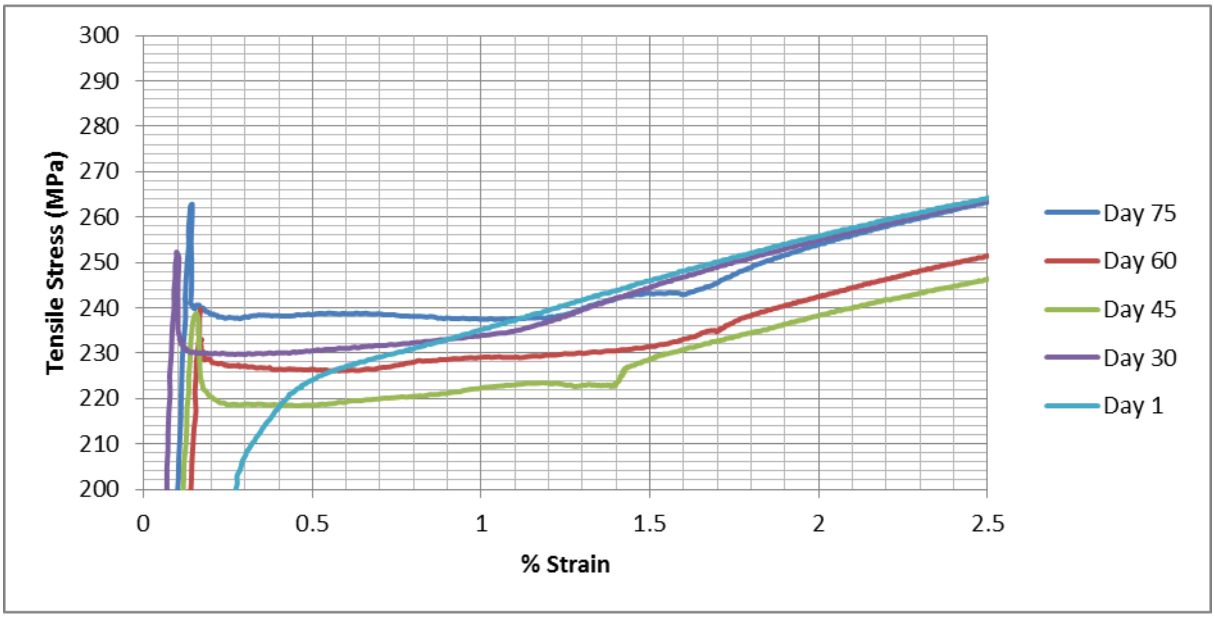


Fig 6 Comparison of YPE for the samples kept at constant temperature oil bath and tested after 15 days intervals

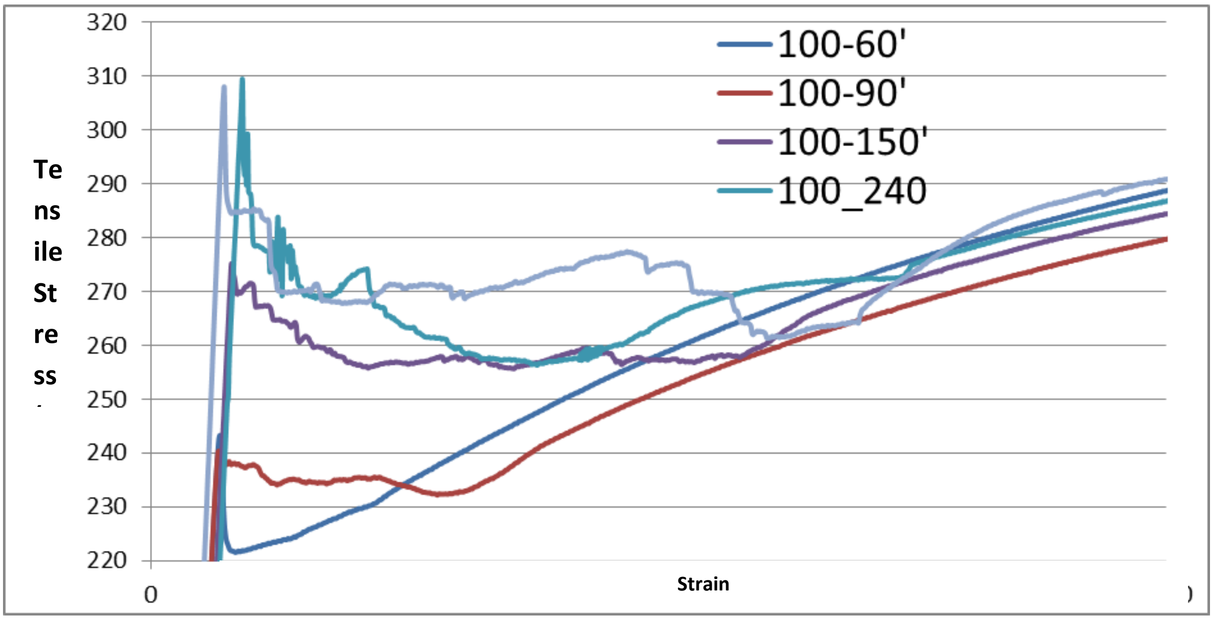


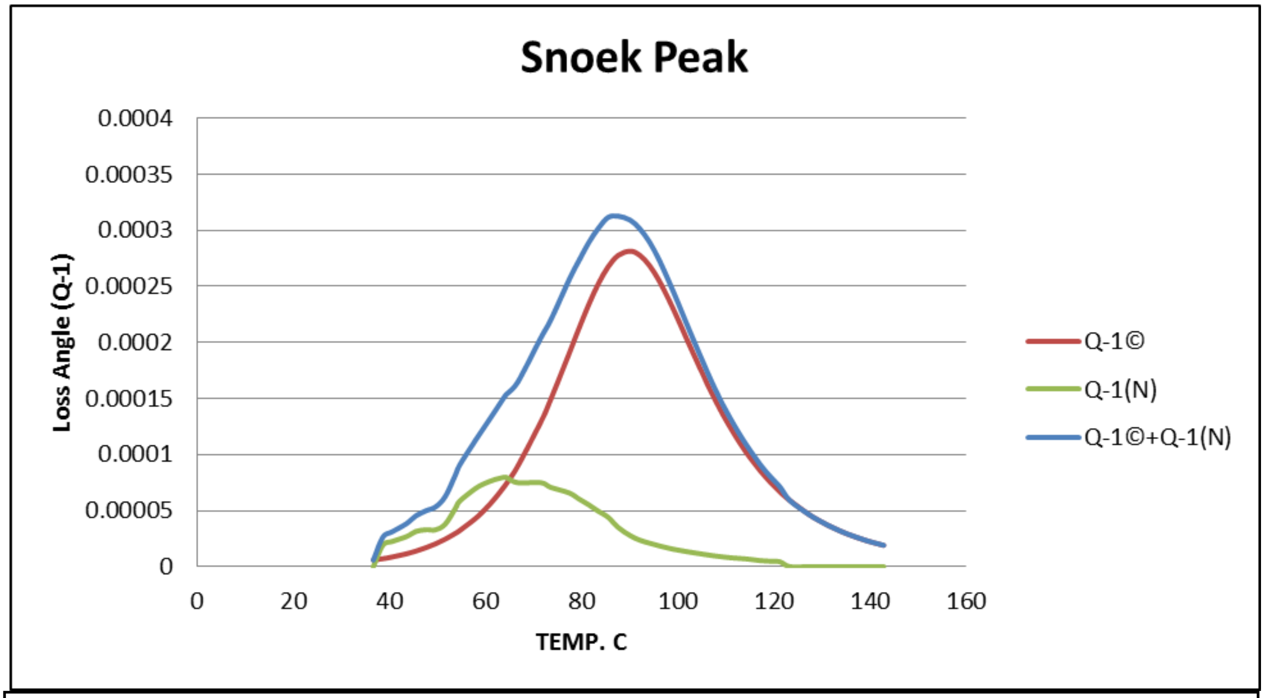
Fig 7 Accelerated strain aging at 100°C for different intervals

The amount of solute elements in this steel was estimated by internal friction measurement with the help of equipment developed in-house. The Snoek-peak height[4] was estimated with this apparatus and the peaks of carbon (Q_c^{-1}) and nitrogen (Q_N^{-1}) were separated. The value of solutes nitrogen (N_s) and solute carbon (Cs) are found by the following two equations respectively.

$N_s = K\, Q_N^{-1}$ where, value of K for N is 4000 ………. (i)

$C_s = K\, Q_C^{-1}$ where, value of K for C is 4400 ………. (ii)

The estimation of Snoek peak and the value of N_s and C_s are depicted in Fig 8



Steel Type/ Solute Elements	C (ppm)	N(ppm)
BH Steel	8.8	1.2
IF Steel	3.0	1.0

Fig 8 Snoek peak and the value of solute nitrogen and carbon estimated from the new internal friction measurement equipment

RESULT AND DISCUSSIONS

Mechanism of bake hardening process and strain hardening phenomenon are associated with the formation of Cottrell atmosphere due to the presence of solute atoms in the matrix. These solute atoms are segregate to pin the dislocations for further movement causing increase in yield strength. Thus, BH property is achieved by keeping an appropriate amount of solute carbon in solution. During paint baking operation at 170^{o} C yield strength increases by solute carbon which locks the mobile dislocations. Some precipitation of carbides may also increase strength due to a second stage of aging at that temperature.

The chemistry of the present sample has been given in Table 1. Where, the C is kept in the range of Ultra Low Carbon Steel. In BA process the mount of solute carbon depends on the total carbon present in steel. With the reducing carbon content, the spacing between solute carbon increases leading to the increase in diffusion distance of carbon in iron and forbid precipitation. As a result, the residual carbons remain in solution and bake hardening occurs in the formed component at paint baking temperature. Nitrogen was kept as low as possible. Aluminium added as de-oxidiser and also interacts with N forming AlN. Solute nitrogen is not desirable due to its higher solubility and diffusivity causes quick room temperature strain-aging. Mn contented in the steel increases the strength as well as the BH value. The average tensile properties of the samples have been given in Table 2 along with its BH value. The n-value indicates a good stretch formability required for skin panel applications. The BH index is on higher side than that of average BH value of similar products indicating the presence of solute carbon on the higher side, 8.8 ppm (Fig 8) and therefore, possibility of limited shelf life is expected for that sample.

Table 2 Average tensile properties a BH Index of the sample

YS Mpa	UTS Mpa	EL %	n-Val	BH-Index *
207	337	41	0.22	52
* BH Index is the difference in flow stress in MPa after baking at 170°C for 20 min and 2% tensile strain				

The yield point elongation were measured from the stress-strain plot of the tensile tests (Fig 6) after taking out samples on the constant temperature oil bath which was set in 40°C. The tensile tests were done for a set of three samples in each 15 days interval and the average value of yield point elongations are given in Table 3. The same has been plotted in Fig 9. It is observed that the yield point elongation crosses 0.2% between 30 and 45 days. In case of the normal samples which were kept at room temperature at laboratory in a non-air conditioned room at temperature about 30±5 °C was not crossed 0.2% elongation even after 90 days (Fig 10), which is the conventional accepting criterion of shelf life for BH grades.

Table 3 Yield point elongation of samples kept in oil bath

No of days kept in oil bath	**% yield point elongation**
1	**0**
30	**0.08**
45	**1.25**
60	**1.46**
75	**1.48**

The prediction of the shelf life the BH samples when kept at 40°C was not followed the conventional industrial correlation based on yield point elongation after accelerated aging test (heating at 100°C for one hour as) as shown in Fig 7, which predicts the shelf life as two months for room temperature. Where, the room temperature shelf life was found as more than 3 months. Again at slightly elevated temperature, at 40°C, depicting the Indian scenario the actual shelf life was drastically reduced to one month (30 to 45 days).

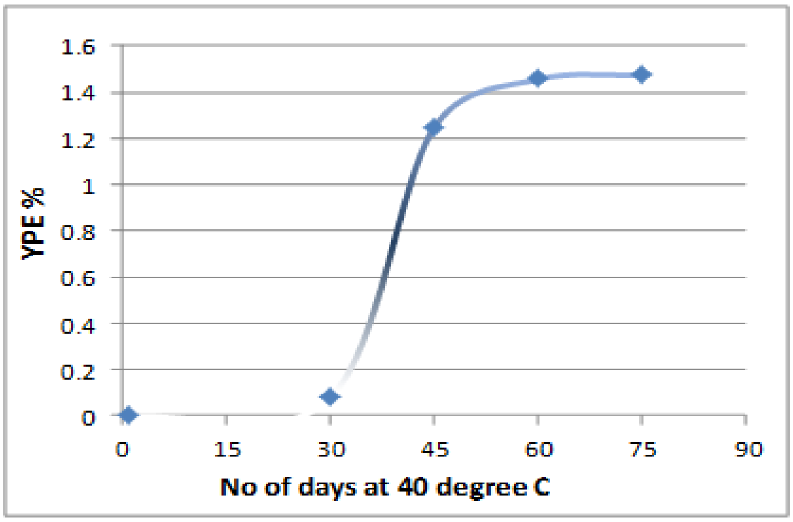


Fig 9 The plot of yield point elongation of samples kept at constant temperature oil bath

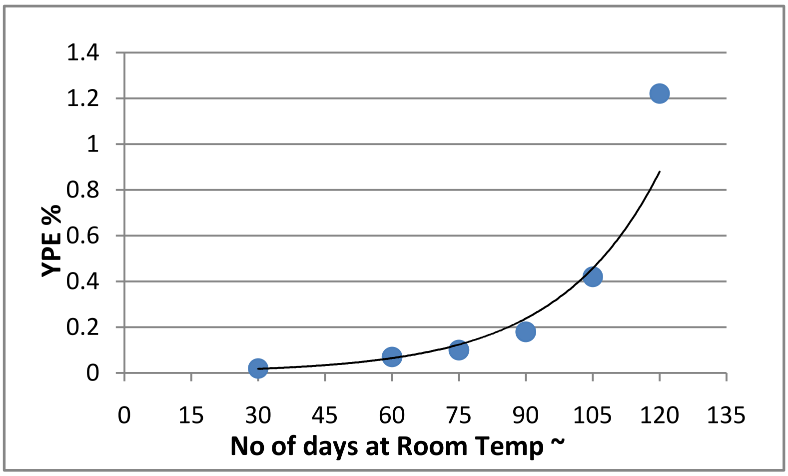


Fig 10 Plot of yield point elongation of samples kept at room temperature

Therefore, to judge the shelf life of the BH grade produced industrially a better method of measurement of solute carbon and nitrogen for each batch of the product. This can be measured with the help of Sinku-Riko Internal friction measurement equipment[5]. From the measurement of the actual shelf life after keeping the samples at a constant temperature an appropriate correlation can be obtained for prediction of shelf life with its solute contents.

CONCLUSIONS

- Prediction of shelf life by conventional stain aging index does not reflect the true material condition.
- Hundy equation and Bhagat-Hundy equation with the modified K-value is found inadequate to predict the shelf life of BH steel at higher than room temperature.
- The actual shelf life of the BH grade was found low when samples were kept higher than the room temperature, depicting India context, except a few month of winter.

- Coil by coil prediction model can be developed for predicting shelf life of BH grade by estimation of solute elements (C and N) present in the material after temper-rolling.
- The weighted average of the warehouse temperature can be adopted with the above prediction to check its remaining life before forming to avoid stretcher stain marks on the final product.

ACKNOWLEDGEMENT

Authors would like to thank R&D and SS department of Tata Steel to equip new facilities like constant temperature oil bath and internal friction measurement for conducting experiments and supports. Authors would also like to thank the management of Tata Steel, Jamshedpur for permission to publish this paper.

REFERENCES

1) Hundy B.B., Metallurgica, 53 (1956), 203

2) Cottrell A.H.and Bilby B.A., Proc. Phys.Soc., 52 (1948), 49

3) Bhagat A. N., Baek S. and Lee H., A simple method for prediction of shelf life of bake hardening steel, ISIJ International, Vol. 48 (2008), 1781-1787

4) Iain G., Ritchie and Zhengliang P, Impurity Interstitial in mild steel, 33rd MWSP Conf. Proc., ISS-AIME, 29 (1992),15-25

5) Kishi A., Introduction to Sinku-Riko Internal Friction Measuring Equipment, Sinku-Riko Inc. (1885)

Improvement in Quality and Optimization of Skin Pass Rolling Load in Titanium Micro-alloyed Extra Deep Drawing Steel

Biswajit Sarkar & Ramen Datta
R&D Centre for Iron and Steel, SAIL, Ranchi, Jharkhand-834002, India
Email: bsarkar@sail-rdcis.com

Bokaro Steel Limited (BSL) produces and supplies low carbon (< 0.04%) extra deep drawing (EDD) quality steel through combined blowing technology (CBT). In response to the demand for higher elongation levels by the customers, measures have been undertaken to improve the elongation levels from 38-42% to 42-45% in case of hot rolled (HR) coils and from 38-43% to 40-46% in case of cold rolled (CR), annealed and skin passed coils. Incidence of rolled in scale has been minimized by ensuring low (950℃) finish entry temperature.

The strategy adopted has involved lowering of C to 0.03% max. by partially replacing medium carbon ferromanganese by high purity (99.7%) Mn, tying up the free N by the addition of ~0.01% Ti and controlling the Si to 0.02% max. by the addition of calcined bauxite, controlling the carryover slag and tapping temperature. De-oxidation has been optimized by reducing Al addition in the ladle furnace in order to restrict the amount of Si. The coiling temperature has been kept at 610-630℃ in case of HR coils, and 540-560℃ for CR coils.

In case of CR and annealed coils, the strain aging index was found to be ~2% compared to ~8% in conventional EDD coils. This enabled the load to be reduced during skin passing of cold rolled and annealed coils by about 50%.

Keywords: Extra Deep Drawing, Micro-alloyed, Titanium, Strain Ageing Index, Elongation

INTRODUCTION

Extra Deep Drawing (EDD) quality cold rolled steel sheets (0.04C-0.15Mn-0.03Si-0.010S-0.015P-0.040Al-70 ppm N) are used in making autobody components. These steels are characterized by high elongation, good formability, flatness and surface quality. Although elongation values may not be directly related to formability parameters like average plastic anisotropy ratio (r_m), strain hardening exponent (n) etc., in India, these cold rolled sheets are still sold on the basis of elongation values. These cold rolled coils are batch annealed for the development of desirable crystallographic texture which leads to high average plastic anisotropy ratio (r_m). After annealing, these coils are skin passed before being shipped to the customers. The purpose of skin passing is twofold; (a) to suppress the yield point elongation which manifests as stretcher strains on the cold rolled and annealed sheets during forming leading to poor surface appearance and (b) to confer flatness to the annealed coils.

Ideally, there should be less than 40 ppm free nitrogen in these steel sheets to achieve the desirable texture of (111) planes lying in the rolling plane and the resultant high average plastic anisotropy ratio ($r_{avg.}$)[1]. However, due to poor control of nitrogen in some of the steel plants, the nitrogen content remains in the range of 70-80 ppm. The excess nitrogen (~30-40 ppm) leads to higher yield strength and lower ductility which is not desirable for forming. Also, higher nitrogen content leads to higher strain aging tendency of these coils. As a consequence, a higher load has to be applied during skin passing of the annealed coils in order to ensure complete suppression of yield point elongation. Application of higher load eats into the ductility of these steel sheets which could otherwise have been passed on to the customers for their end use.

A stoichiometric addition of ~0.01% titanium (3.42N) in the steel is expected to tie up with the excess nitrogen of ~30-40 ppm. The present note reports the effect of the addition of ~0.01 % titanium to these EDD steel on the properties of the cold rolled and skin passed coils. A decrease in strain aging, as measured by Strain Aging Index (SAI) has been observed in the cold rolled and annealed coils. This has led to the optimization of load during skin passing of these coils with a consequent increase in ductility without compromising on the formability parameters.

STRATEGY FOR IMPROVEMENT

Upon detailed analysis of the process for the production of EDD steel at BSL, the following points emerged.

Carbon

It is well known that a decrease in C leads to an improvement in the product quality in terms of lower yield and tensile strength and higher elongation. Conventionally, BSL had been producing EDD steel with <0.04% C. By fully exploiting the combined blowing technology (CBT), it was possible to decrease C further to <0.03%. However, there is a limit beyond which C cannot be reduced, based on thermodynamic considerations. It has, therefore, been decided that the medium carbon ferro-manganese, which is conventionally added will be partially replaced by the addition of high purity Mn metal to restrict C.

Silicon

Si increases the YS and decreases the total elongation values. Usually, the Si in EDD grade steel at BSL is ~ 0.03%. It has been decided that this would be brought down to < 0.02% in the final product. During the process of desulfurisation, Si enters into liquid metal (Fig. 1) after SiO_2 of slag and refractory is reduced by Al in steel by the following reaction:

$$3\,\{SiO_2\} + 4\,[Al] = 3\,[Si] + 2\,\{Al_2O_3\} \qquad \ldots\ldots\ldots\ldots\ (1)$$

This can be slowed down by reducing the activity of silica in slag with modification in flux practice. The modification involves the addition of high purity bauxite, which contains Al_2O_3. With increase in Al_2O_3 activity in secondary refining slag at different stages of LF refining, the SiO_2 activity in slag is reduced (Fig 2) and the silica deoxidation reaction is retarded. The phenomenon of silicon reversal could be further controlled with control in thermodynamic and kinetic factors like low temperature operation and reduced stirring rates at LF. With combination of these parameters Si reversal reaction to liquid metal could be retarded to a great extent and 84.5% heats with Si < 0.02% in final product could be produced.

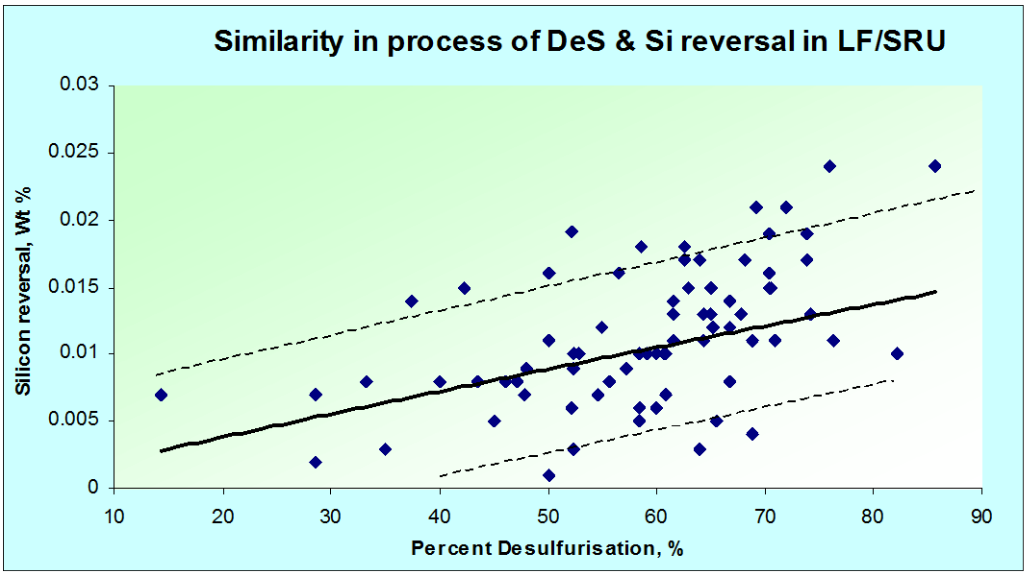


Fig 1 Plot showing silicon reversal into the hot metal as a function of desulfurisation

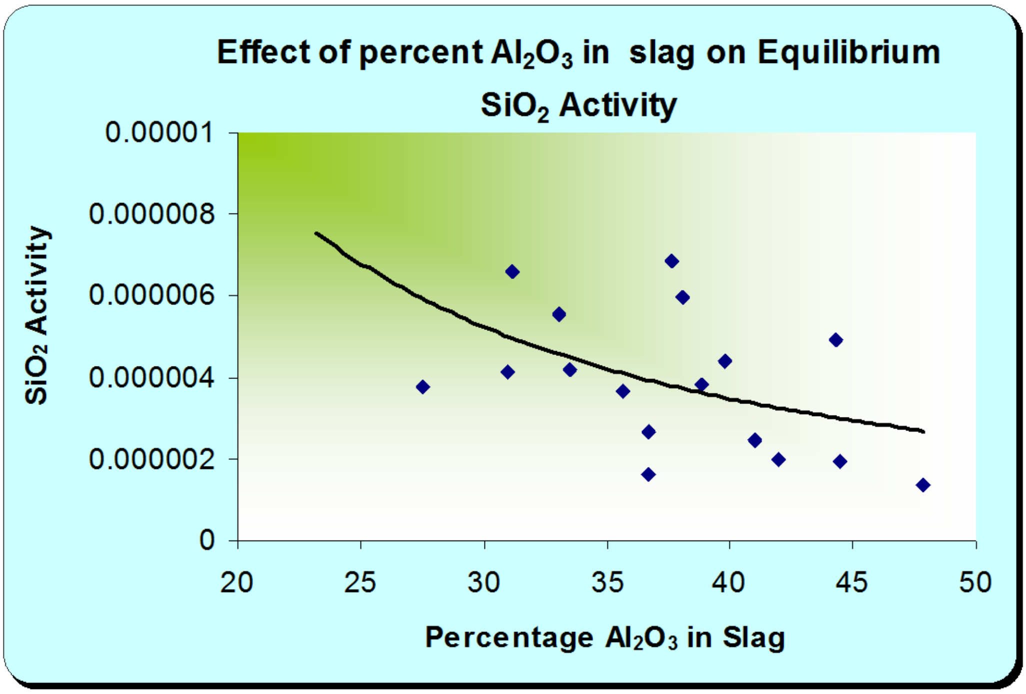


Fig 2 Effect of alumina in the slag on the activity of silica

Nitrogen

Desirable level of total N in EDD steel is about 40-45 ppm. However, it was found that total N in the EDD grade produced at BSL lay in the range of 70-80 ppm which is quite high. This level leads to about 30 ppm free N dissolved in steel which is not desirable. Free N deteriorates the total elongation and leads to an increase in the YS. It is also responsible for room temperature strain ageing of the CR and annealed EDD steel which is undesirable.

The presence of excess N is because of inadequate control of oxygen purity in oxygen plant. During processing of the steel oxygen (of purity ~ 98.5-99%) is blown into liquid melt at BOF and hence uncontrolled N pickup occurs during concluding stage of oxygen blowing into the hot metal. Subsequent removal of N is difficult during vacuum treatment in LF for steels having low C and low S[2]. N is additionally picked up during poor stream shrouding between ladle to tundish during casting and during annealing after cold rolling.

In view of the lack of proper control of N, it was decided that an attempt would be made to tie up the free N (~ 30 ppm) by Ti. Hence a near stoichiometric (Ti = 3.42N)[3] addition of ~ 0.01% Ti was made in the experimental heats.

PLANT TRIALS

Experimental heats have been made with < 0.03% and < 0.04% C with the addition of ~ 0.01% Ti. These have been continuously cast into slabs, hot rolled into coils of thicknesses varying between 3.2 and 5 mm. The finishing temperatures varied in the range of 880-900°C while the coiling temperatures varied between 620°C and 640°C in case of coils which were dispatched in the HR condition. The CR had lower coiling temperature (550-570°C). These have been pickled, cold rolled, annealed and skin passed.

Experimental

Material

Around 0.01% titanium addition was made in a few heats of EDD steel of nominal composition 0.04C-0.15Mn-0.03Si-0.010S-0.015P-0.040Al-70 ppm N. These were continuously cast into slabs. The slabs were then hot rolled in the hot strip mill with a finishing temperature of 880-900°C and coiling temperature between 550-570°C. The width of the coils was ~1250 mm. The hot rolled coils were pickled in hydrochloric acid and were given a cold rolling reduction of ~70%. The cold rolled coils were batch annealed in bell annealing furnaces at ~700°C. The total annealing time was about 54 hours. The coils were finally air cooled.

Skin pass rolling of the annealed coils

The annealed coils were skin passed with a conventional load of ~600T and a reduced load of ~300T. Samples were taken from annealed coils i.e. before skin passing, after skin passing with ~600T load and ~300T load.

Tensile test

Tensile samples having a gauge length of 80 mm and width 20 mm were prepared from EDD coils with and without titanium. Samples were prepared at different stages of i.e. before skin passing, after skin passing with conventional load of ~600T as well as with reduced load of ~300 T. These samples were tensile tested at a cross head speed of 2 mm/min in Instron 1195 tensile testing machine.

Determination of Strain Aging Index (SAI)

Tensile samples were prepared from coils without titanium and with titanium. Samples from coils were obtained before skin passing as well as after skin passing in coils containing titanium. These tensile samples were pulled up to 7% strain which is well past the yield point elongation. The flow stress at 7% (σ_7) was recorded. These were heated (aged) in boiling water for one hour. These were again subjected to tensile test till fracture. Flow stress (σ_a) after aging was recorded. SAI was calculated as follows:

$$SAI\ (\%) = (\sigma_a - \sigma_7)*100 / \sigma_7 \qquad \ldots\ldots\ldots\ldots\ (2)$$

RESULTS AND DISCUSSION

Fig. 3 shows the effect of skin passing load on the SAI and elongation in cold rolled and annealed conventional EDD coils without titanium. The Strain Aging Index (SAI) in these coils before skin passing is ~8%. A load of ~600T is required to skin pass the coils of 1250 mm width (thickness: 1.2 mm) to completely suppress the yield point elongation and to render these coils non aging (SAI =0). With this load there is a loss of about 5 % in total elongation (Total elongation decreases from 44% before skin passing to 39% after skin passing. Fig. 4 shows the effect of skin passing load on SAI and elongation values for titanium added EDD coils. It is apparent from the figure that due to a lower SAI of 2.1 % before skin passing, the load required for rendering the coils non aging is only ~300T which is half of the load that is necessary for skin passing of conventional EDD coils. As a result of the application of lower load there is a gain of 2.4% in total elongation in the final product in case of Ti micro-alloyed EDD steel compared to conventional EDD steel (Fig. 3 and 4). It was further observed that a decrease in the skin passing load did not adversely affect the flatness of the skin passed coils.

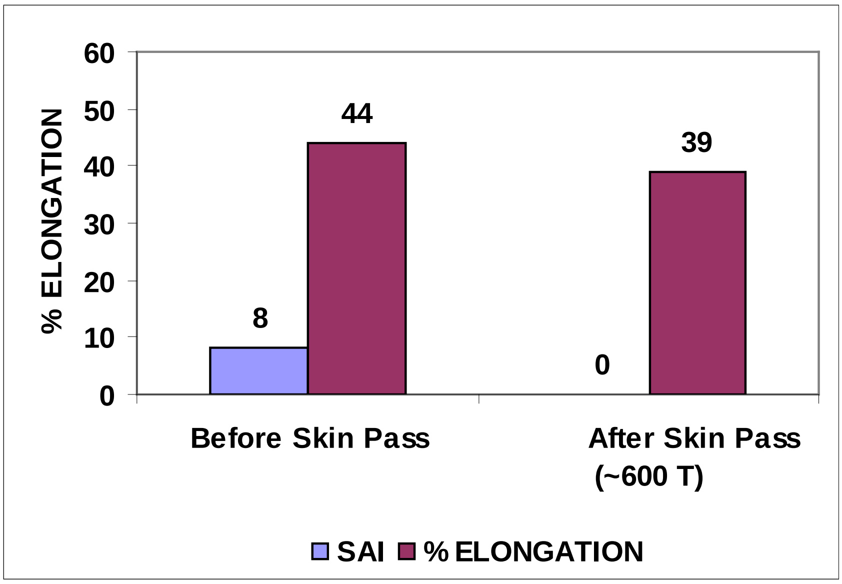


Fig. 3 Effect of load during skin pass rolling on elongation & SAI of conventional EDD steel

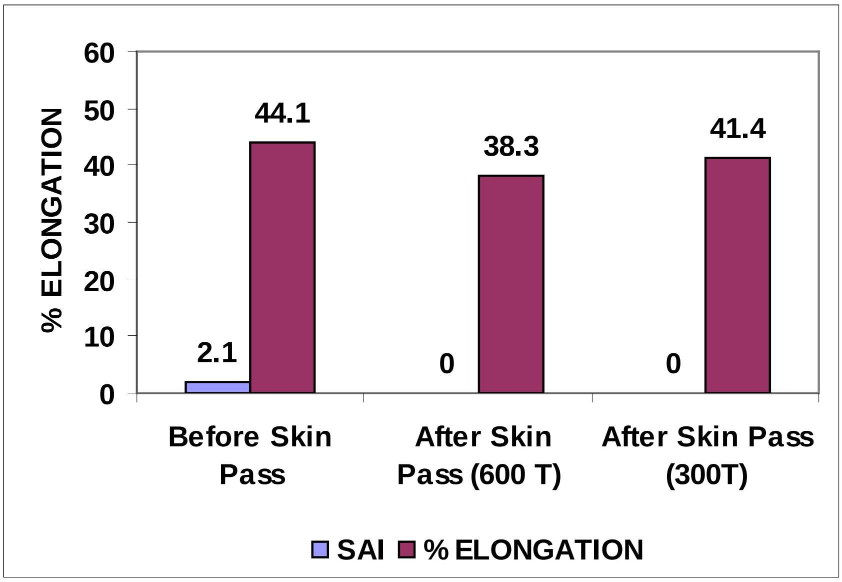


Fig. 4 Effect of load on SAI & elongation during skin pass rolling of Ti-bearing EDD steel

To sum up the findings, addition of ~ 0.01% titanium has led to a decrease in strain aging tendency of cold rolled and annealed EDD steel coils which has enabled a reduction of load during skin passing of these coils in order to render them non aging. There has been only a marginal decrease in average plastic anisotropy ratio. Further, it has been observed that a lower load during skin passing has not adversely affected the flatness of the final product.

CONCLUSIONS

Addition of small quantity of Ti (~0.01%) led to reduced free nitrogen in the steel and resulted in an improvement of total elongation by 2-3% compared to conventional EDD steel sheets without Ti. There is a substantial decrease in SAI as a result of titanium addition of ~0.01% in the cold rolled and annealed coils of EDD quality steel. SAI decreases from ~8% in case of conventional cold rolled and annealed coils without titanium to ~ 2% in titanium micro-alloyed cold rolled and annealed EDD coils. As a result of a decrease in SAI, the load during skin passing of cold rolled and annealed Ti micro-alloyed steel can be reduced from ~600T for conventional EDD steel to ~300 T, without adversely affecting the flatness of these coils, thereby gaining 2-3% in total elongation value in the final product.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support provided by the managements of RDCIS and BSL for the execution of the project. Involvement of Shri S.K. Maitra in different activities related to plant trial, and testing merits our sincere appreciation. Last but not the least, help received from the laboratory staff is gratefully acknowledged.

REFERENCES

1) M. Takahashi, A. Okamoto, S. Ino, and T.Nakata, Trans. Iron and Steel Inst. Japan, 1979, 19, 144- 151

2) R. J. Fruehan, Ladle Metallurgy Principles and Practices, 42, The Iron and Steel Society, 1985

3) G. Tither and H. Stuart, HSLA Steels ’95, ed. L. Guoxum et al., Beijing, Chinese Society for Metals, 22-31

Process Optimization for Microstructure evolution of Annealed Cold Rolled Steel

B Sunita Minz[1], Santosh Kumar[2] & Roselin Dodrae[1]
[1]SAIL, Bokaro Steel Plant, Bokaro Steel City, Jharkhand-827011, India
[2]SAIL, RDCIS, Bokaro Steel City, Jharkhand-827011, India
Email: sunitajane@gmail.com

Bokaro Steel Plant is in progress on machinery rehabilitation in different mill sections and commissioning of new 1.2 MT cold rolling mill (CRM) will be used to produce high-quality steel grades for applications in the automotive industry. The new rolling mill consists of a coupled Pickling Line-Tandem Cold Mill (PLTCM), an Electrolytic Cleaning Line (ECL), Bell Annealing Furnace (BAF) and a Hot Dip Galvanizing Line (HDGL). The purpose of this study is to assess the impact of cold rolling reduction of 80-92% and hydrogen annealing in BAF with high efficiency of heat transfer on mechanical properties of low carbon grade steel and then aim to characterize the microstructural evolution of the material for annealing process optimisation. Mechanical properties such as yield stress, ultimate tensile stress, elongation, hardness and r-bar have been evaluated for different grades of low carbon steel processed under different conditions. These results are then verified by microstructural characterization, using techniques such as optical microscopy, electron backscatter diffraction (EBSD) in the scanning electron microscope (SEM) and transmission electron microscopy (TEM).

Heat treatment with controlled rate of cooling for arresting grain growth and surface modification are the key technologies to enhance the effective use of materials and to achieve the desired properties of the material used in the automotive industries. The tested parameters of annealing, mainly temperature and time together with other factors like total cold reduction have the decisive influence on the microstructure and hence mechanical properties after annealing. Strength and drawability properties of the material decrease with increase in annealing temperature whereas, on the contrary, plastic properties increase.

Keywords: Microstructural Evolution, Annealing Process Optimization, Cold Rolled Steel

1.0 INTRODUCTION

Lighter vehicles with enhanced safety and energy consumption are the needs of the automobile industry and the use of high strength steel can help comply with the statutory requirements. Focusing on the increasing demands of this sector, the construction of the new state-of-the-art cold rolling mill at Bokaro Steel Plant and the technology employed will enable production of high quality cold-rolled products for applications in the automotive industry.

EDD grade steel has continued to maintain its position as a major input material for manufacturing various components of intricate shape both for light and commercial vehicles. Today, automotive manufacturers demand superior quality steel with higher level of formability, weldability and paintability to facilitate easy and defect free production. Structure and resulting material properties are significantly influenced by cold rolling. Extension of grains in the direction of rolling occurs and the arrangement of crystallographic lattice gets a directional character. Factors influencing the final character of microstructure after annealing are: the initial character of material structure before cold forming, the total cold reduction, annealing conditions (temperature and time) and also rate of cooling.

The annealing process is one of the important operations in the sequence for producing cold rolled steel sheets, which significantly influences the final product quality of cold rolling mills. At Bokaro Steel Plant, hot rolled steel is reduced in thickness on high-powered rolling mills without reheating the steel from hot roll thickness (1.6 to 5.0mm) to finish thickness (0.25 to 2.0mm) undergoing a reduction of at least 80-92%. This method is used to get uniform thickness, increase thickness tolerances, and improve strength and a smooth surface finish through strain hardening. Though cold rolling has these advantages, the ductility of the cold rolled steel is reduced due to the dislocations. In order to achieve the desired properties, the steel is heated in Batch Annealing Furnaces (BAF) to recrystallize the internal structure, creating a softer and more workable material. Annealing is done in a controlled gas atmosphere consisting of nitrogen and hydrogen gases in various compositions. Batch annealing operation of a secondary cold-rolling mill has numerous operational challenges, including processing of input coils with high variability and lack of customized cycle design for individual stacks.

The purpose of this study is to assess the impact of cold rolling reduction of 80-92% and hydrogen annealing in BAF with high efficiency of heat transfer on mechanical properties of low carbon grade steel.

2.0 EXPERIMENTAL PROCEDURE

The input material for the experiment was low carbon hot and cold rolled steel strips of thickness 1.2 to 0.6mm followed by annealing in BAF (different HT cycles) and temper rolling / skin pass rolling. Chemical composition of the experimental grade of steel is presented in Table 1.

Table 1 Chemical Composition of Tested Steel (%)

Sample	%C	%Mn	%P	%S	%Si	%Al
AIM	0.04-0.08	0.15-0.22	0.015-0.022	0.003-0.010	0.046-0.08	0.018-0.08
Sample-1	0.04	0.15	0.016	0.005	0.056	0.023
Sample-2	0.05	0.19	0.020	0.009	0.061	0.040
Sample-3	0.06	0.18	0.015	0.003	0.046	0.041
Sample-4	0.06	0.21	0.022	0.003	0.079	0.044
Sample-5	0.05	0.20	0.020	0.003	0.045	0.039
Sample-6	0.06	0.15	0.018	0.004	0.048	0.034

The slabs were heated in reheating furnace and soaked at a temperature of 1250-1280°C. Then these slabs were passed through vertical scale breakers, edgers and 5 - roughing stands. The plates coming after roughing stands were fed into seven 4 high stand finishing mill to produce strips of thickness ranging from 1.6 mm to 5.0 mm and width 930 to 1830 mm for cold rolling. The finishing rolling temperature was 880±10°C and coiling at 680±10°C. The cold reduction was from 80-92% followed by annealing with different heat treatment cycles.

As cold rolled structure is shown in Fig 1, which exhibits strained & elongated ferrite structure. Different heat treatment cycle was deployed for evolution of desired microstructure.

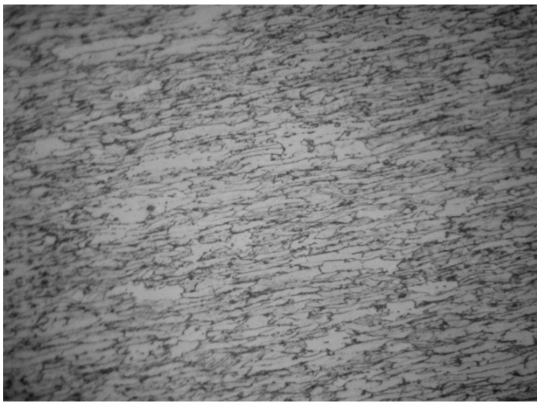


Fig 1 As Cold Rolled structure

Sample - 1 & 2 was given annealing treatment having indirect heating medium inside inner cover with Protective gas with 5% H_2 and 95 % N_2. The Heat Treatment Cycle (HT Cycle-1) employed for experimenting the coils are shown in Fig 2(a) & 2(b).

Sample-3 was given annealing treatment in Hydrogen medium (HT-2). The samples have been drawn from coils subjected to annealing heat treatment at BAF and then skin passed.

Sample - 4, 5 & 6 were given annealing treatment of HT Cycle-3, 4, & 5 respectively in hydrogen media.

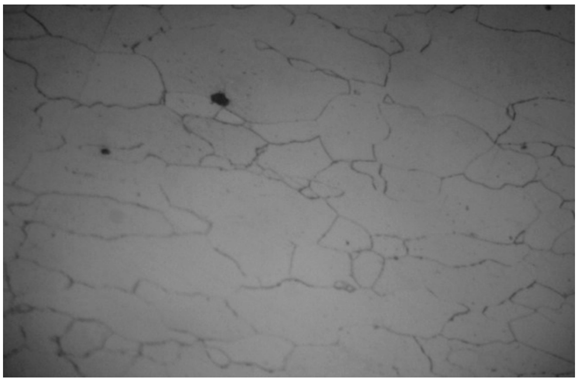
Table 2 Experimental Batch annealing cycle (in hrs)

	Initial heating duration	**Intermediate Soaking at 450°C**	**Final Heating duration**	**Final Soaking at 710°C**
HT-1	10	8	10	7
HT-2	8	5	9	7
HT-3	8	6	8	7
HT-4	8	5	12	7
HT-5	6	4	8	10

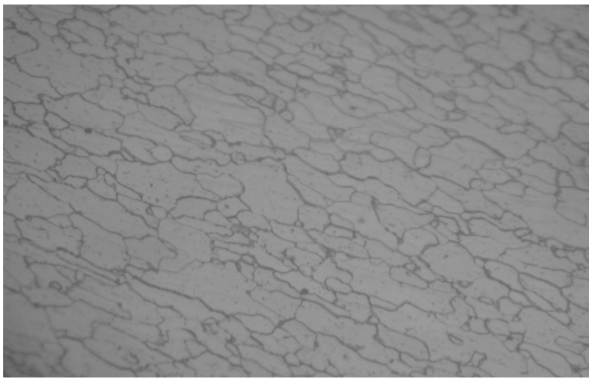
3.0 RESULTS

The alloy chemistry designed aimed at 0.04% -0.08% C, keeping in perspective the steel making practices of BSL, Bokaro.

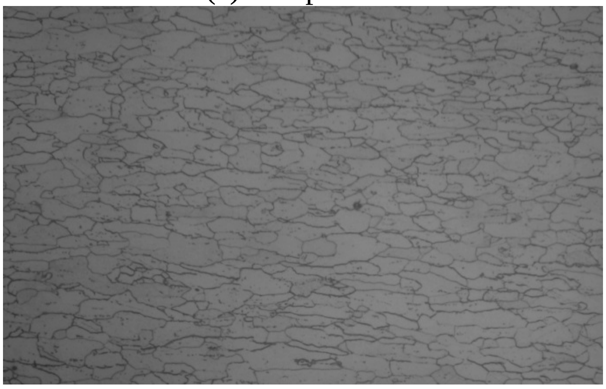
The samples for evaluation of structure were taken from 2nd lap of rolled out products (in the perpendicular section, parallel with the direction of rolling). The structure was evaluated from selected samples after annealing. The samples were polished in etched with 2% Nital and observed under the optical microscope to study the microstructure and observation are recorded with the photomicrographs is given in the table below:



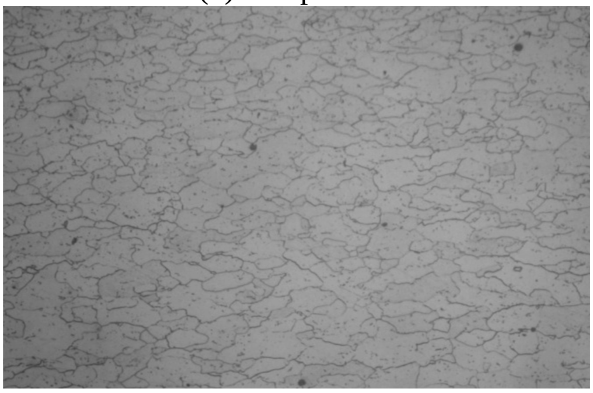
(a) Sample-1



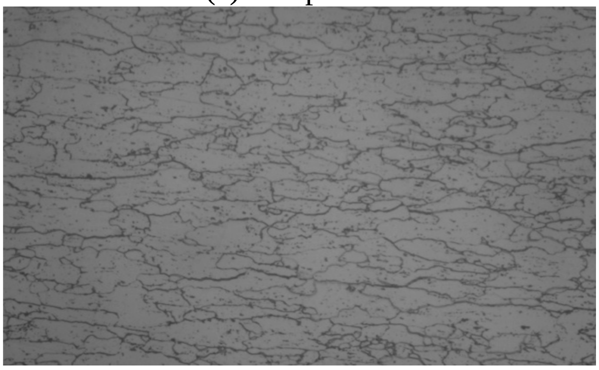
(b) Sample-2



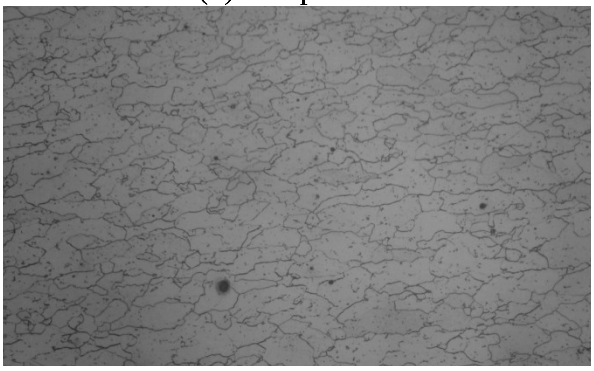
(c) Sample-3



(d) Sample-4



(e) Sample-5



(f) Sample-6

Fig 2 Microstructure of experimental steel (Low C Steel)

In Fig 2(a), the microstructure showed coarse ferrite matrix with cementite at the boundaries and within the grains. The stucture showed equiaxed grains with average ferrite grain size of 8 ASTM No.

In Fig 2 (b), the microstructure showed ferrite matrix with cementite at the boundaries and few within the grain. The stucture is slightly pancake shaped ferrite grains.

In Fig 2(c), microstructure reveals pancake shaped ferrite grains with cementite within grains.

In Fig 2(d), microstructure reveals almost pancake shaped ferrite grains cementite granules within the grains and close to the boundary. The average ferrite grain size of the sample is 9.5 ASTM No.

In Fig 2(e), microstructure reveals almost equiaxed shaped ferrite grains cementite granules within the grains and close to the boundary.

SEM analysis of grain boundary area in low carbon steel (sample-4) annealed at 710°C and with intermediate soaking at 450^{o}C can be seen in Fig-3. The micrograph shows cementite precipitates in the matrix of ferrite.

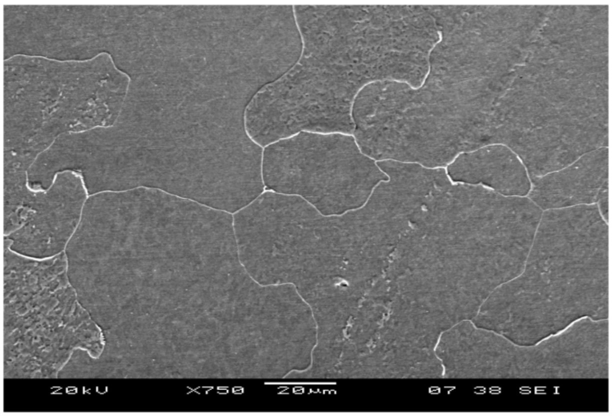


Fig 3 SEM image of grain boundary area (sample-4)

Physical Properties:

Mechanical properties such as yield stress, ultimate tensile stress, elongation, hardness and r-bar have been evaluated for different grades of low carbon steel processed under different conditions. The results obtained are given at Table 3

Table 3 Mechanical properties of experimental grades of steel

Coil No.	Hardness (in VPN)	YS (MPa)	UTS (MPa)	% El	r-bar
Sample-1	44	207	319	36	1.2
Sample-2	46	217	325	33	1.5
Sample-3	41	227	324	40	1.3
Sample-4	44	213	342	43	1.6
Sample-5	43	219	344	42	1.5
Sample-6	42	205	293	44	1.5

4.0 DISCUSSIONS

The optimized sheet properties are attained as a result of interaction between two processes: carbide & AlN precipitation and recrystallization. Apart from pancaking of grains, the number distribution and morphology of carbides also play a role in formability. Smaller, spherical, and larger in number of carbides give good formability, because in this way the ferrite contains less C (ferrite is purer), which helps formability. Therefore, in order to improve the property of deep drawing sheet it is important to control every processing step effectively.

Since the favourable microstructure & texture for high deep drawability is obtained in the pancake grain structure, the processing parameters are set to obtain pancake structure, while transition zone structure is avoided since the latter results coarse grains (ASTM<8) leading to reduced ductility. Experimental results also show that high degree of pancake structure has high r-bar and % elongation.

The microstructure varies with heating rate and soaking duration and mechanical properties and r-bar are strongly dependent on heating rate during annealing. Batch annealing cycles normally involve slow heating up to about 700°C with intermediate soaking at 450°C.

Experimental evidences point towards a good correlation between the effect of an element on the activity of carbon in ferrite on the one hand and the site of carbide precipitation on the other.

Precipitation of cementite on grain boundary causes the enhancement of fracture susceptibility due to generation of micro cracks at the interface of ferrite and grain boundary cementite, and consequently deteriorates post uniform ductility. On the contrary, the precipitation of finer carbides in the ferrite matrix contributes to increase in post uniform elongation value and this means improvement in post uniform ductility which have ultimately resulted in higher percentage elongation.

Silicon significantly increases the carbon activity in both ferrite and austenite and decreases its solubility in ferrite. As a result, Si inhibits the formation of cementite. It has extremely low solubility in cementite, thus, it affects the nucleation of this carbide. It is believed that the accumulation of Si around a cementite nucleus could considerably increase the C activity which prevents its diffusion to nucleus. These concept also supported by this experiment where Sample-2 has slightly high Si content, which shows high hardness as well as UTS, YS but have low elongation.

Soaking temperatures of the order of 1200-1250°C are necessary for carbon & nitrogen remains in solution. In addition, the recombination of Al with N also needs to be prevented during cooling and coiling after hot rolling. To attain this, the finish rolling temperature must be high enough and above Ar3 followed by fast cooling in the AlN precipitation range in association with low coiling temperature (<600°C), to avoid poor ductility and drawability in the annealed steel.

Slow heating after cold rolling is normally necessary to allow adequate time for the Al to diffuse, forming clusters or precipitates before recrystallization commences. Thus, low heating rate leads to the precipitation of AlN during recovery that helps generate strong {111} texture after recrystallization. The precipitation of AlN takes place at a lower temperature and this is followed by recrystallization of the steel at a higher temperature.

5.0 CONCLUSION

The microstructure evolution of cold drawn 0.04-0.08% C steel has been analyzed. At lower soaking time, recovery of the deformed grains is pronounced. The hardness of the material reduces with increasing annealing temperature for all the degree of cold deformation indicating increasing recrystallization with increasing annealing temperature. The recrystallization kinetic is characterized by prolonged recovery at lower soaking time and rate of recrystallization increases with increasing degree of cold drawn deformation. Particular trends of the strength and plastic properties correspond to each other and they may be utilized for optimization of annealing terms of the investigated low C steel in a cold rolling mill, exactly in accordance with specific requirements.

With the fact that mechanical properties can vary a lot as per customer requirements, it is not possible to set up a common annealing mode that would be the most appropriate. Specific requirements of strength and plastic properties can be obtained by optimization of different terms of heat treatment of the examined low carbon grade steel in a cold rolling mill.

ACKNOWLEDGMENT

The authors thankfully acknowledge the help and support extended by the management of Bokaro Steel Plant and R&D Centre for Iron and Steel.

REFERENCES

1) I. Schindler, M. Janošec, E. Místecký, M. Rùèka, L. Èí□ek, L.A. Dobrzañski, S. Rusz, P. Suchánek, Archives of Materials Science and Engineering, Vol. 36 Issue-1, 2009, P. 41-47

2) J. Garcia-Vargas, D.A. Hardwick, W.M. Williams, Control of Mechanical Properties in Low Carbon Steel Using an Anneal – Strain – Anneal Method, Canadian Metallurgical Quarterly 19, 1980, P. 333-343.

3) Nurudeen A. Raji, Oluleke O. Oluwole, "Recrystallization Kinetics and Microstructure Evolution of Annealed Cold-Drawn Low-Carbon Steel", Journal of Crystallization Process and Technology, 2013, 3, P.163-169

4) Auburn P & Rocquet P, Mem. Science Review Met, Vol-LXX, No 4, 1973, p. 261

5) Beranger G, Henry G & Sanz G, The book of steel, Springer-Vertag, USA, 1994, P.935-951

6) I. Schindler, M. Janošec, E. Místecký, M. Růžička, L. Čížek, L.A. Dobrzański, S. Rusz, P. Suchánek, , Influence of cold rolling and annealing on mechanical properties of steel QStE 420 Archives of Materials Science and Engineering Vol. 18 Issue-1-2, 2006, P. 231-234

7) Wang Su-Fen, Peng Yan, Li Zhi-Jie, Work-Hardening and Deformation Mechanism of Cold Rolled Low Carbon Steel, Research Journal of Applied Sciences, Engineering and Technology 5(3): 823-828, 2013

Steel Making, Refining and Casting of Auto Steel

D Ravichandar & Sudhakar Asawale
JSW Steel Ltd, Salem Works, Salem, Tamil Nadu-636453, India
Email: d.ravichandar@jsw.in

In making of steel for auto industry, challenges faced in the long products domain includes improving the fatigue life of components such as bearing and crankshaft, torsional resistance in springs made of high carbon steel axle shaft, reduction in noise level of gear box, machinability for making intricate precision components, cost reduction in processing through micro alloys, improved reliability of components through control of internal and surface cracks and high strength to weight ratio for fuel efficiency.

Steels with consistent chemical composition and suitable heat treatment ensure fine microstructure in the steel matrix. Besides this, steel cleanliness plays a major role in the improvement of fatigue life. Need of the day is to standardize the secondary refining practice involving de-oxidation with Aluminium / Silicon as appropriate, inert gas bubbling with bubble size control and multiple porous plugs, vacuum degassing, slag engineering to target lower oxygen levels etc. The level of Oxygen, Hydrogen and Nitrogen has comedown drastically in recent times. Sulphur and Phosphorus reductions pose different type of challenges. Levels of micro and macro inclusions as well as the carbide banding have gone down less than 50% of what it was. Testing equipment like SEMs, Phased Array UT, MFL, Infrared Surface Detection, Immersion Ultrasonic etc are replacing conventional equipment today.

Keywords: Fatigue Life, Inclusions, Micro-alloys, Heat Treatment, Secondary Refining

1 INTRODUCTION

1.1 Indian Auto Industry

The Indian auto industry is one of the largest in the world with an annual production of 23.37 million vehicles in FY 2014-15, in view of a growth rate of 8.68% over the last year. The automobile industry accounts for 7.1% of the country's gross domestic product (GDP)[1]. By 2020, India's share in the global passenger vehicle market is expected to be 8% from 4% in 2010–11. Currently India is ranked the second largest in two wheeler, third largest in passenger car and fourth largest in commercial vehicle manufacturer. The compounded annual growth rate (CAGR) was 11%, 10%, 9% and 9% for the production of passenger vehicle, commercial vehicles and two and three wheelers respectively in the last 10 years. Two wheeler production in India is likely to increase from 18.5 million in FY2015 to 30 million by FY2025[2]. The passenger car sales will triple by 2025, on the strong demand from the rise in the income level.

1.2 Special Steel for Indian Auto Industry

Alloy special steel plays key roles in manufacturing of many critical components in various industries; automobile industry being the largest. The applications of alloy steel are becoming increasingly diverse and advanced. The special steel production in India was 4.8 MTPA in FY 2014 and 75% of the special steel goes to automotive industry[3]. Bearing Steel, spring steel, forging quality steel, free cutting steel, tool steel etc. are some of the steel grades produced in special steel industry. These grades are widely used in the making of crank shaft, connecting rods, leaf springs, helical spring, seamless tubes, wire ropes etc. Special steel industry is expected to grow at a CAGR of 9% and will reach 10 million tons in next 8 years[3].

India being a vibrant economy is fast becoming a manufacturing hub for automobile as well as auto component manufacturing sectors, which are witnessing a rapid growth with more investment by global automotive OEM's. The likely investments by them will be to the tune of 60,000 crores in the coming years.

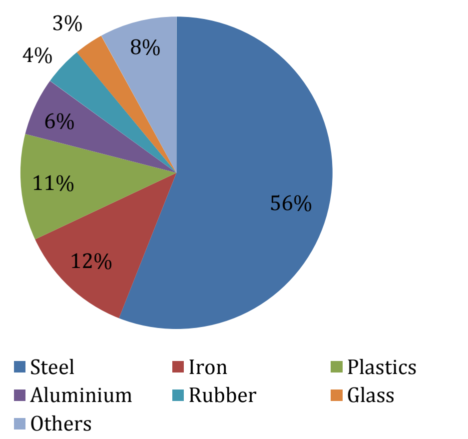


Fig 1 Materials in a Passenger Car

The typical expectations of the growing automobile sector are fuel efficiency, fool-proof safety features, low noise, high reliability in performance, high strength to low weight ratio etc. These expectations manifests itself into imposing stringent requirements on the quality of raw materials, as it is going to be transformed into automobile steel constituting 56% of its weight in passenger car, out of which 36% is made out of flat products and 20% is made out of long products (Fig 1). At JSW, Salem Works, more than 350 grade variants are developed, out of which, about 90 grades accounts for 83% of the total special steel demand. Chrome-manganese, chrome-moly and carbon steel account for 65% of the special Steel demand. Wire rods from size 5-24 mm account for 92% of the overall wire rod demand, fasteners forms the significant consumer segment. 75 RCS (round cornered square) alone contributes to 30% of RCS demand and majority of the demand is for forging applications and almost 78% of rounds are less than 100mm size range. Three major special steel exporting countries are China, South Korea & Japan of which china alone contributes 43%. Alloy steel, CHQ steel and micro alloyed steel accounts for 62% of the imports.

2 SPECIAL STEEL DEVELOPMENT

Today's automobile is required to give optimum performance in terms of fuel efficiency, comfort of travel, comfort of driving, crash worthiness, safety and reliability among others.

a. Fuel economy calls for efficient combustion of fuel as well as reduction in weight of the automobile.
b. To ensure comfort of travel, the suspension system of the vehicle needs to be excellent besides other features in the interior.

c. The development of power steering, efficient transmission and traction system is going a long way in ensuring the driving comfort and also reduction in noise and vibration.
d. Development of high strength steels capable of withstanding heavy impacts encountered in a crash.
e. The endurance life of each component needs to be guaranteed to assure the reliability of functioning of vehicle.

The alloy special steel used for automobiles is expected to have the following characteristics to meet the above mentioned demands.

a. Uniform and narrow band in chemical composition
b. Low levels of tramp elements
c. Low levels of dissolved gases
d. Low density of macro inclusions
e. Uniform distribution of sulphide inclusions for machinability
f. Sulphide inclusions with low aspect ratio
g. Grain size control
h. Freedom from internal defects like cracks
i. Uniform microstructure
j. Excellent surface quality viz. free from seams

The measures taken at JSW, Salem Works, to achieve the required characteristics of special steels are mentioned in Table 1.

Table 1 Measures taken to achieve characteristics of special steel

Demands by Automotive User	Automotive Offering	Counter measures
Fuel Economy	Weight reduction	Development of material for parabolic spring instead of traditional laminated springs
		High tensile steel flat products manufactured at JSW Vijayanagar, for automobile body parts.
Safety measures	Crash worthiness	High strength of steel
	Prevention of premature failure of components	By increasing cleanliness of steel as well as reduction of internal/surface defects
Low Noise	Control of component dimensions	Control of uniformities of chemical composition
		Grain size control
	Increase in Bearing life	Reduction in macro inclusions
	Increase in fatigue life	Uniform microstructure
High Reliability of components	Close control of properties desired	Maintaining narrow ranges in chemical composition and other properties

2.1 Fuel efficiency

Making cars and trucks lighter helps to improve fuel economy. Hence, auto makers are trying to reduce the overall body weight of vehicle to improve the fuel efficiency by developing components that are lightweight and still possess sufficient strength, durability, corrosion and wear resistant to meet safety requirements. Steels micro alloyed with vanadium, niobium and titanium are found to possess sufficiently high strength and toughness. Hence, efforts are being taken in this direction to make various micro alloyed steels with desired micro structure, which are of light weight. JSW, Salem works, has taken initiatives to produce micro alloyed steels meant for the production of parabolic springs to replace conventional laminated springs without compromising the load carrying capacity. Development of 51CrV4 grade as a replacement of SUP 9 and SUP 11A has made this possible.

High strength wire springs require good control of uniform, fine and pearlitic microstructure with least amount of grain boundary carbides coupled with lower amount of interstitial elements like nitrogen to control strain hardening thereby improving the drawability (Fig 2). Sulphur and phosphorus are other elements which affect the flying fracture phenomena and hence are controlled to below 0.008% and 0.015% respectively.

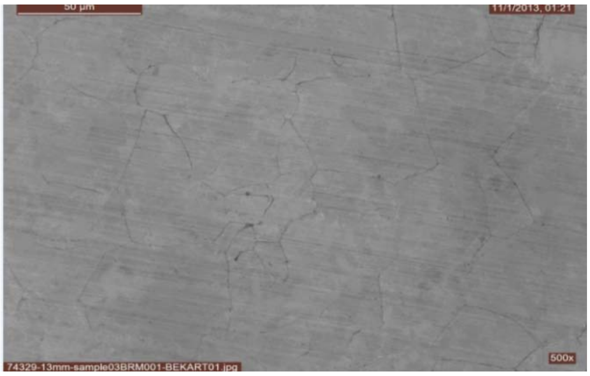


Fig 2 Grain boundary carbides in spring

2.2 Freedom from internal defects (cracks, porosity etc.)

Reduction of dissolved gases to a lower level ensures lower partial pressure of combined gases during solidification leading to freedom from porosity and blow holes. Low level of hydrogen is achieved by vacuum degassing to ensure steel free from hydrogen flakes/hairline cracks. Proper selection of casting powder, secondary cooling, support system for cast bloom below mold and appropriate balance of chemistry and EMS ensures freedom from hinge, midway and center cracks. At JSW, Salem Works, steel cleanliness is achieved through:

2.2.1 Control of tramp elements

Increased levels of tramp elements cause deterioration in surface quality and mechanical properties of certain steel grades. Tramp elements like Bi, Sn, Sb, Cu, As etc remain as residual elements in steel and causes embrittlement by segregation to grain boundaries. It is controlled mainly through the selection of raw materials.

2.2.2 Control of dissolved gases

About 600-800 ppm of oxygen is observed at the time of tapping. Early strong deoxidation during tapping is practiced to remove dissolved oxygen. The bath is maintained in deoxidized condition through regular addition of deoxidant and efficient slag engineering. Final oxygen levels of less than 15 ppm and the best value of 6-7 ppm could be achieved.

Hydrogen is removed in vacuum degassing to less than 1.5 ppm by judicious selection of time, argon flow and vacuum pressure below 1 mbar. Further pick-up of hydrogen in tundish can be minimised through appropriate heating cycle of tundish and spray mass quality. Nitrogen is reduced to a level of 60-70 ppm in vacuum degassing under low level of surface active elements like oxygen and sulphur. The precision levels for various parameters achieved at JSW, Salem Works is presented in Table 2.

Table 2- Precision levels for various parameters achieved at JSW, Salem works

Sl	Parameter	Unit of measurement	Normal Levels	Improved / Precision levels
1	Oxygen	ppm	15-20	8-15
2	Nitrogen	ppm	75-85	65-75
3	Hydrogen	ppm	1.8-2.0	< 1.5
4	Sulphur	%	> 0.005	0.003-0.004
5	Phosphorus	%	> 0.015	0.010-0.012
6	Carbide banding	Microns	100-120	50-60
7	Micro inclusion	Index	10- K4 Index	<5 - K3 index
8	Macro inclusion in 45 dia bars	mm/dm^3		$< 14\ mm/dm^3$

2.3 Low noise

Good dimensional control is a pre-requisite for the good mating surfaces of gears and to produce less noisy gear box. The major factors affecting the dimensional control are close control of chemistry and fine grain size to give minimum distortion after case carburizing treatment. The demand on controlling the coarsening of grain size increased due to cost optimization processes used by customers like cold forging of components and higher temperature of 975^{o}C for case carburizing. To avoid the coarsening of grain size higher amount of soluble aluminium level along with more than 100 ppm nitrogen level needs to be maintained. This particularly poses problem to make clean steel under these conditions. JSW has succeeded in designing processes (uniform chemical composition, grain size control, reduction in macro inclusion, uniform microstructure etc.) to achieve these conflicting requirements from customers.

2.3.1 Uniform chemical composition

- Variation in chemical composition from heat to heat is controlled during melting in a narrow range through predictable recovery of alloying elements through standardized melting and deoxidation practices. Narrow range in chemistry followed for making a typical grade is presented in Table 3.
- Selecting appropriate cast section also helps in controlling segregation.
- Segregation control is achieved through control of superheat, constancy of casting speed, secondary cooling practices and effective mold EMS.

Table 3- Chemical composition of a typical grade

Grade	C%	Si%	Mn%	P%	S%	Cr%	Al%	N ppm	O_2 ppm	H_2 ppm
20MnCr5	0.20-0.22	0.28-0.33	1.30-1.38	0.020 max	0.020-0.030	1.20-1.24	0.015-0.030	80 max	15 max	2 max

2.3.2 Grain size control

Many automobile components need to withstand impact loading and must possess sufficient toughness. Presence of fine grains structure increases toughness in steels which are used in quench and tempered condition. Fine grain size is achieved at higher heat treatment temperatures through judicious manipulation of Al/N ratio and the respective contents of Al and N.

2.3.3 Low density of macro-inclusion:

Low levels of macro inclusions are achieved through strong deoxidation early in the process, appropriate slag chemistry and proper floatation using rinsing practices at the end of secondary refining. The cleanliness is maintained through prevention of reoxidation by argon flush of tundish, free opening of ladles and avoidance of clogging.

2.3.4 Uniform microstructure:

Low level of segregation is achieved through control of superheat, effective use of EMS and secondary cooling, which in turn reduces alloy segregation / banding. Furthermore, controlled cooling practices after rolling, ensures reduction in phase banding.

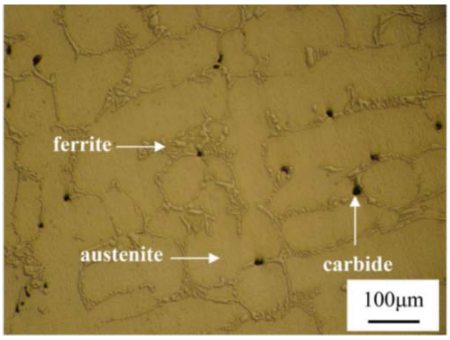


Fig 3 Titanium carbonitrides in steel

Higher fatigue life of components is achieved through very high level of cleanliness, uniform microstructure preferably tempered martensite, smooth surface finish of components and surface free from compressive stresses. Steels with consistent chemical composition and suitable heat treatment ensure fine microstructure in the steel matrix. JSW has standardized the secondary refining practice involving de-oxidation with aluminium / silicon as appropriate, inert gas bubbling, vacuum degassing, slag engineering to target lower oxygen levels (<10 ppm) in case carburizing steel and less than 8 ppm in through hardening bearing steel to ensure low inclusion count of less than 5 on K3 index. Bearing quality steel for races is being manufactured with as low as 20 ppm titanium and carbide segregation is restricted to a level of 6.1 & 7.2 (Fig 3). The most modern SEM-EDS (Scanning Electron Microscope) with Image analyzer are being used to characterize the inclusions and XRF spectrometer was used to design slag chemistry.

2.4 Improved reliability of components through control of internal and surface cracks

JSW practices 100% vacuum degassing to minimize hydrogen levels to minimize internal hairline cracks. Technologies like high pressure primary descaling, walking beam / hearth furnaces, secondary descaling, control on the roll life and other actions has enabled to produce steel bars, wire rods, flats without surface defects. This has resulted in increased customer confidence and loyalty, reduction in expenditure on inward inspection, rework and product liability.

2.5 Improving steel machinability

The machinability changes due to the presence of various elements, for instance, sulphur enhances machinability by combining with Mn to form MnS (Fig 4). Machinability is further improved by the addition of certain modifiers, which changes the morphology of non-metallic inclusions resulting in improved machinability. The addition of modifiers has been found to improve the uniformity of distribution of inclusions resulting in improvement in machinability.

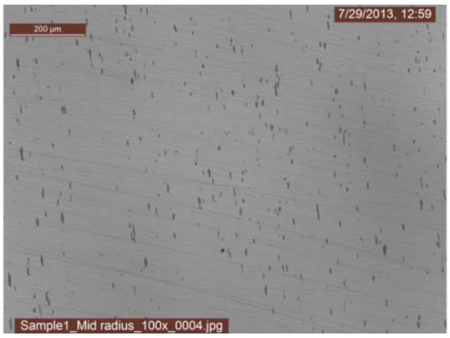


Fig 4 Sulphide inclusion in steel

Though steel machinability is a system response, factors such as, steel having less hard oxide inclusions and uniformly distributed manganese sulphide and morphology with inclusion aspect ratio from 1 to 4 were found to play important roles in determining its machinability. A typical example being, steel used for crankshaft posed problem with internal cracks due to very low Mn/S ratio making the steel prone for hot tearing. The problem was solved by optimizing the chemistry within the customer specified range, controlling the cooling parameter, alignment in caster & switching over from square blooms to round blooms. Machinability is further improved by the addition of modifiers, which were found to improve the uniformity and the number of distribution of inclusions resulting in improvement in machinability. Another example being, the demands imposed on a free-cutting steel to satisfy cold heading properties and high machinability. The problem was solved by optimizing its chemical composition with respect to S, Pb, Si and oxygen to give 70% cold upset ability as against a minimum of 50% and machinability of more than the bench mark of 9000 components standard achieved with best imported material.

2.6 Cost reduction in processing through micro alloy steel development

Two types of micro alloyed steels were developed. The first category consisted of boron steels, which were extensively used for critical fastener applications having consistency in chemistry, better response to heat treatment and cold forgeability.

Second category consisted of medium carbon manganese type of steels with higher sulphur levels ranging from 0.04-0.07% and nitrogen levels ranging from 100-200 ppm, developed for extensive use in 'as forged' condition for crankshaft application, which precludes subsequent quench and tempering heat treatment process. The major challenge was to control sulphur within a narrow range of 0.015% without adversely affecting steel cleanliness at higher nitrogen levels. JSW has succeeded in producing 5 different grades for crankshafts applications in trucks and cars.

2.7 Environmental Benefits

Improvements in the quality of steels results in increase in the life of automobile components. As a result of which, the number of components needed to be made per year decreases with a corresponding decrease in carbon foot print.

3 TECHNOLOGICAL FACILITIES USED

3.1 Scanning Electron Microscope

- SEM with magnification up to 300000X
- EDS for point analysis and mapping
- Failure analysis of samples to find root cause which facilitates adjustment (or) fine tuning and standardize the process

3.2 Auto Inspection Lines for Round and RCS Bars

- Auto inspection line for bars from 20mm to 180mm to find surface and internal defects with recording and data storing systems
- Phased Array UT System – Defect Detection Sensitivity up to 0.70 mm FBH and 0.50 x 10 mm SDH
- For Surface defect detection – MFL and IR with defect detection sensitivity ≥ 0.30 x 10 mm
- 100% volume coverage in round bars and in RCS dead zone is limited to 5 mm max at corners
- Increased accuracy in detection, sizing, location and orientation of all critical defects

3.3 Roll RSB Kocks Block in BRM

- Free-size rolling of all finished sizes from 20.6 to 60 mm Ø
- Computer aided control system for accurate adjustment of roll passes and roller guides.
- Close tolerance rolling of bars to 1/3rd of its standard tolerance limits.
- Average ovality reduced from 0.40 mm to 0.25 mm for Bars.
- Improved Surface finish

3.4 Immersion Ultrasonic Testing

- Used to determine macro cleanliness of steel

Fig 5 Technological facilities used

4 CONCLUSIONS

Availability of state of the art testing and analytical tools such as SEM-EDS, Phased array and immersion ultrasonic testing, Hydris analyzer, Optical Emission Spectrometers, X-ray Fluorescence Spectrometer, Gas analyzers etc., have been instrumental in developing more than 700 product standards and more than 90 single source customers in auto sector. New technologies, collaboration with external knowledge centers in India and abroad, technological tie-up with research organizations and undaunted will and never die attitude of skilled and committed work force leads us in the right direction to overcome future challenges and to gain competitive edge. The company focuses on more value addition to be more price competitive. The technological and skill level also has improved a lot to compete with world class steel makers both in price and quality fronts. Special steel grades such as tire cord, ball bearing, transmission gear, cold headed quality for fasteners etc. are currently imported by India due to unavailability of superior technology. Our efforts are all focused in replacing such grades by import substitution through in-house R&D development and technological tie-ups with educational institutions and research organizations.

ACKNOWLEDGEMENT

The author is thankful to the management of M/s. JSW Steel Limited, for granting permission and for providing facilities to carry out experiments in blooming and bar and rod mills.

REFERENCES

1) Automobile industry in India-Market share by volume (FY15), Available from http://www.ibef.org/industry/india-automobiles.aspx, Sep, 2015

2) News letter, Metallurgy Materials Engineering, Indian Institute of Metals, Vol. XCII, Issue no. 92/2015, Available from http://iim-delhi.com/upload_publication/IIM-Newsletter_Sept2015.pdf, Sep, 2015

3) Unpublished results of market survey conducted by Feedback consultants, Mumbai for JSW, Salem Works

IMPROVEMENT IN SURFACE QUALITY FOR AUTO GRADE STEEL

A K Roy

Bokaro Steel Plant, Bokaro-827011

Email: ashok_indian001@rediffmail.com

Auto grade steel are generally advanced high strength steel which includes Dual Phase (DP), Complex-Phase (CP), Ferritic-bainitic (FB), Transformation-Induced Plasticity (TRIP) and Hot–Formed(HF) and Martensitic and boron-based Press Hardened Steels (PHS). These grades steels are complex in nature and sophisticated material. The scales formed during hot rolling in these grades are very complex and tenacious in nature. During the hot rolling or heat treatment of this type of steel, complex oxides of iron forms on the surface. These oxides or scales need to be removed before steel is further processed in cold rolling mill. Since the surface quality of auto grade steel is very important parameters, non removals of scale not only give bad appearance to the product but also accelerate corrosion. During cold rolling of the strip scale patches affects the reduction with the possibility of the skidding of rolls. Effective scale removal is essential for the success of not only for cold rolling but also of subsequent annealing for auto grade steel.

Main defects in cold rolled steels are black patch, overpickling, underpickling, pitting on surface, acid and water carry over causing dull surface, roll mark, poor trimming. The prominent defects are generated in pickling lines therefore to produce material with improved surface quality we have to address the problem generated in pickling lines. The basic problem in pickling line is acid carry over, poor acid bath management, water carry over and trimming. Thus we find that most of the problem in pickling line is related to acid tank management. Keeping all these in view the older sulphuric acid based pickling lines have been gradually phased out which were giving dull, smut and spotted surface which is not desirable for auto grade steel. The Sulphuric acid as such doesn't react with the top layer of oxide causing problems in removing the scales or oxides formed during hot rolling so cracking of oxide layers are must before going for pickling. However the pickling speed is low and the surface finish is still not very satisfactory for complex steel like auto grade.

In Bokaro Steel Plant, Pickling Line-1 was H_2SO_4 acid pickling processing line. Keeping in view the above problems the modernization of tank area was necessary for producing better finished pickled surfaced coils for further processing in cold rolling mill. Due to this disadvantage, sulphuric acid pickling line has been converted into a fully automated Faplac system Hydrochloric (HCL) pickling line consisting of scale breaker, pre-rinse, FRP pickling tanks with shallow tanks design, recirculation tanks with acid heating and circulation, rinse section, strip dryer and fume exhaust system. With the commissioning of HCL line, there is an improvement in productivity and surface quality. It consistently produces uniform light gray surface and absolutely free from scale. The over pickling is much less than H_2SO_4 pickling. Effective pickling is obtained with uniform acid concentration which is maintained automatically. The new HCL pickling line is capable for producing auto grade steel.

The main sections of HCL pickling tanks are:

- Entry Section:
  - One steering unit
  - One tension leveller device
  - One strip support rolls and loop measuring unit device

- Process Section
  - One pre-rinse tank
  - One pickling and intermediate tanks set
  - One spray rinse tank
  - Circulation systems
  - Fume exhaust and treatment system
  - One edge blow off and strip dryer system
  - Sump pumps
  - Wringer rolls
  - One steering roll unit
  - Ventilation system
  - Special fire fighting system
  - Interconnecting piping
  - One wringer roll changing car

- Exit Section
  - One bridle
  - One deflector roll

- Auxiliary units
  - Hydraulic system
  - Lubrication system
  - Pneumatic system

GENERAL DESCRIPTION OF THE NEW HCL PICKLING LINE SECTION

Entry Section

Strip coming out from the entry looper passes through a steering unit to ensure good strip guiding before entering the tension leveller

<u>Tension leveller equipment</u>

At the exit of the steering unit, two entry bridle rolls units are foreseen: entry bridle rolls #1-2 and entry bridle rolls #3-4. All these rolls ensures the necessary tension to the strip inside the Tension leveller machine by amplifying the tension coming up from the entry looper.

Inside the Tension leveller machine the strip is subjected to a combined effect of elongation and flexion around small diameter work rolls, in order to have both flattening and scale removing effect on the strip.

At the exit of the Tension leveller machine the exit bridle rolls #1-2 and the exit bridle rolls #3-4 ensure the necessary tension to get the required elongation and the proper back tension inside the process section.Each bridle roll is driven by a dedicated electrical single motor via a single own gearbox unit.

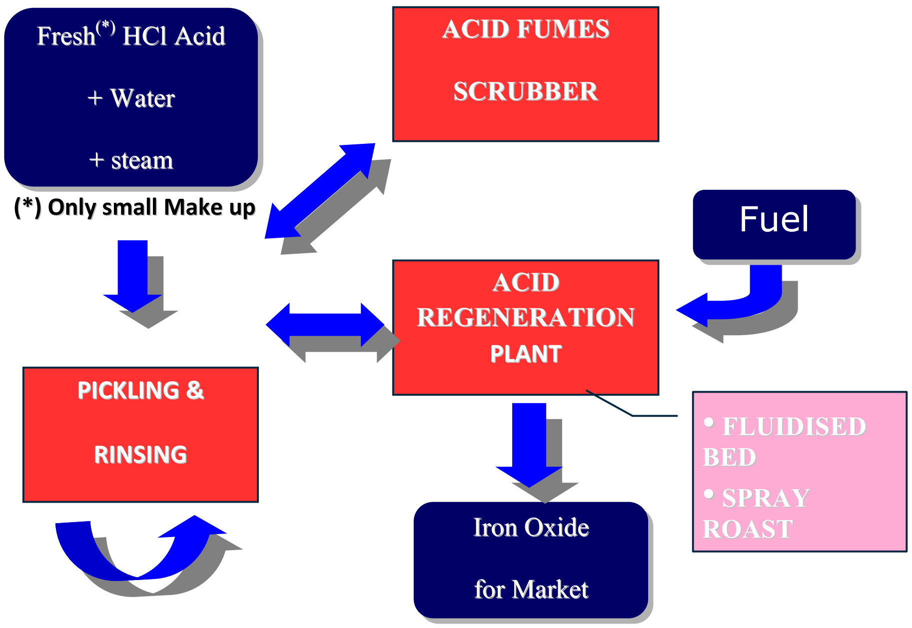
A scale exhaust system provides to extract the scale powder from the Tension leveller machine. The scale powder is extracted by fans, collected by bag filters and finally discharged into a collecting box.

The strip then passes through a catenary detecting system to measure the tension applied to the strip.

Process Section

A new high-performance effluent-free strip pickling lines has been developed. These technological evolutions can meet the requirements of cost-effectiveness, improved product quality and an environmentally safe process, combined with minimized maintenance requirements. The combination of new pickling technologies and regeneration plants for waste pickle liquor makes it possible to operate pickling plants minimizing wastewater and pollution.

Here following a simple scheme to represent all the flows involved in the so-called "LOW WASTE PLANT".



The process section is designed by considering the pickling requirements of the incoming material qualities. Consequently the strip surface is pickled in a smooth way, over pickling is suppressed and the consumption of chemicals and energy as well as the production of emissions are efficiently controlled.

The pickling process section is consisting of the following equipment:

- Pre-rinse section
- Pickling section with three latest generation shallow tanks
- Pickling tanks with acid heating and circulation system
- Rinse section cascade spray type
- Strip dryer (with edge blowing system)
- Fumes exhaust and treatment system
- Instrumentation

Pre-rinse tank is designed for rinsing the strip in case of emergency pullback operation and it is done to protect upstream equipment against acid contamination.The pickling proper takes place in the cascade HCl pickling tanks.

The scale layer on the strip is chemically dissolved by the acid as follows:

80°C

$FeO + 2HCl \longrightarrow FeCl2 + H2O$

80°C

$Fe2O3 + xHCl \longrightarrow 2FeCl2 + 3H2O$

80°C

$Fe3O4 + xHCl \longrightarrow 3FeCl2 + 4HO2$

In the pickling bath the cascade system results in a stepwise concentration of the dissolved scale and free acid between the pickling cascades as shown in the following block diagram. This concentration gradient highly improves the pickling efficiency and permit sufficient pickling results that can join up to 130 g/l of metal in the exhausted solution.

To reach this result, one pair of squeegee rolls is located inside an overflow chamber between two consecutive pickling tanks, to reduce as much as possible the acid solution dragout from the upstream tank to the downstream tank. In this way only a small amount of solution richer of Fe flows from previous tanks to the next ones and the concentration drop of dissolved Fe and of free HCl between two consecutive tanks is maintained high and fairly constant, thus improving the acid solution exploitation.

Another factor that improves the pickling effect is the acid solution circulation system designed to increase the pickling bath turbulence. As the pickling tanks design is shallow type with reduced depth, the level of the acid solution inside is depending on the strip speed: the higher is the speed, the more is the increase of level of the acid solution towards the tank exit end. To counterbalance this effect and to limit the consequent big overflow of the acid solution into the next overflow chamber, a counter flow spray ramp is put above the strip pass line at entry of the overflow chamber, a series of lateral nozzles are put on both tank sides and eject the acid solution counter flow the running strip; finally another spray ramp is put above the strip pass line at entry of the tank to wet with acid solution the entering strip.

The circulation system of the tanks is arranged with circulation/storage reservoirs. The acid solution is pumped from each circulation/storage reservoir to the correspondent process tank by centrifugal pumps passing through graphite type heat exchangers. From each process tank the acid solution flows back by gravity to the correspondent circulation/storage reservoir by overflowing into two overflow chambers that are located one before and one after the process tank. The circulation/storage reservoirs are also used to collect the acid solution from the corresponding process tanks that are drained by gravity through bottom discharge valves in case of prolonged stop of pickling section and the return pipes are sized large enough to keep the drainage time as short as possible (generally less than 5 minutes).

The cascade circulation from the exit end to the entry end of the pickling section is achieved by gravity through the circulation/storage reservoirs that are connected each other by connection pipes.

As the tanks are designed to match with their bottom profile the natural catenary shaped pass line of the running strip, they remain naturally full of acid solution besides the overflow at exit imputable to strip speed, so the circulation pumps can work at relatively low pumping head (about 0.25 to 0.3 MPa) and don't need to operate at variable speed. Only in case of strip running at minimum speed some pump of each tank can work in short circuit (circulation not through the process tanks, but through the circulation/storage reservoirs) and in case of line stop all pumps work in short circuit through the circulation/storage reservoirs to maintain warm the acid solution for a quick restart. By this installation the restart of the pickling section back to the operation conditions is guaranteed particularly short (approx. 2.5 minutes).

In the pickling circulating system, the following data are controlled:

- The level in each circulation reservoir to protect the pumps from cavitation. In the first circulation tank the level is also monitored to adjust the exhausted acid solution flow rate to be sent to the ARP.

- The temperature of acid solution delivered to the process tank is measured downstream the exchanger to regulate the quantity of steam to be fed to the heat exchanger.

- The flow rate of the regenerated acid and of the additional make up water is controlled to feed in the correct proportion the relevant quantity to be delivered to the last circulating/storage reservoir. One density meter is provided on the discharge line of exhausted acid solution to the ARP to monitor continuously the iron content. This measure is used as a feedback to the acid recirculation system mathematical model to adjust the flow rate of the regenerated acid solution to the last pickling tank. The mathematical model is consisting of a series of algorithms that put in correlation the requested flow rate of the regenerated acid with the main running parameters of the line and with the characteristics of the material to be processed. Due to the measure drift of the density meter a laboratory check about every shift should be done to reset the instrument.

To get high turbulence of the acid solution in the pickling tanks and to increase the relative speed between strip and pickle agent, the acid solution is injected into the pickling tank counter-flow respect the running strip. The injection nozzles are distributed along the sidewalls of the pickling tanks, thus achieving uniform temperature and concentration distribution. Additional spray bars are located at the entrance of the pickling tank allowing direct chemical interaction of the strip surface with the scale and immediate heat transfer into the strip

Another advantage of the acid injection from the sidewall is that the turbulent flow of the acid solution results in particularly efficient pickling effect on the heavier scale layer at the edges of the strip.

To make the running strip to match as much as possible the catenary shaped profile of the process tanks bottom, the specific tension applied on the strip is controlled by means of a free catenary measuring unit ahead the entry side of the pickling section.

After the last pickling tank and inside the last overflow chamber one double squeegee rolls unit is provided to reduce the acid solution drag-out to the following rinsing section and to limit consequently the quantity of rinsing water requested to clean away the acid solution residuals from the strip surface. The double squeegee rolls unit is also including an automatically controlled steering mechanism to correct possible off tracking of the strip.

The rinsing of the strip is performed by means of a cascade spray rinse section. The rinsing section is then divided into five compartments separated one from the next one with squeegee rolls units.

Each compartment of the rinsing section is consisting of a process tank where the rinsing water is collected in its bottom and one pump circulates the collected water to a series of spray ramps, one half of them put above the running strip and the other half below. The water is collected in the compartments at different levels that are decreasing from the last compartment to the first one, so the water overflows in cascade in the opposite sense respect the running strip.

The rinse water overflowing from the first compartment is collected in a collecting reservoir and is partially used as make-up water in the pickling section, while the balance is sent to the Regeneration plant.

The condensate coming from the heat exchangers of the pickling section is conveyed to a reservoir where it is mixed with demineralised water and steam. The content of this reservoir is then used as hot make up water for the last compartment of the rinse section. A conductivity meter controls that the condensate is not contaminated by acid leakages inside the heat exchangers, both to give a malfunction alarm and not to contaminate the make-up water to be used in the rinsing section.

After the last compartment of the rinsing section one double squeegee rolls unit is provided to limit as much as possible the transport of rinse water on the running strip surface towards the following drying unit, that is entitled to remove any trace of moisture from the strip surface.

The drying unit is of the hot air type, including one edge blowing unit to mechanically remove the residual water transported especially by high thickness strip, for which the squeegee rolls efficiency is less, and by a vaporizing unit to remove the moisture that almost uniformly covers the strip on its full width.

Two independent blowers are provided to supply the drying unit, the one medium capacity and medium pressure to feed the edge blowing unit, the other one high capacity and low pressure to feed the vaporizing unit.

The air to be fed to the vaporizing unit is also to be heated by means of a steam-air heat exchanger.

Both the edge blowing and the vaporizing unit are housed inside a soundproof cabin to suppress the noise of the air coming out at high speed from the relevant distributors.

Exit Section

After the process section, the strip passes through the bridle rolls unit no. 5, made by two motorised rolls, then through a motorised deflector roll that reduce the strip tension down to the operating tension in the existing exit loop car.

Major improvements

1. Better surface finish
2. Efficient utilisation of acid and water
3. Better fume exhaust system
4. Cost efficient
5. Environmental friendly system

Advanced High Strength Steel Hot Rolled Coils Production for Automotive Industry

Matteo Remy Bulfone[1], Sanat Bhaumik[2] & Santanu Rudra[2]
[1]Danieli Wean United, Italy
[2]Danieli Wean United, India
Email: sk.bhaumik@india.danieli.com

India is one of the fastest growing market for automotive industry and by 2020, it is expected that car production in the country is likely to be almost 8 million units requiring more than 7 million tons of automotive steel. The major automotive steel producers in India are Tata Steel, JSW, POSCO with Bhushan Steel supplying some quantities of automotive steel to car manufacturers located in Northern India. SAIL and ArcelorMittal are planning for a joint venture 1.5mtpy plant which may start production in 2019-20. But there is lot more space for new plants to come up to meet the demand of 7 million tons by 2020. Top steel companies in the country, are therefore, increasing their manufacturing capacity of automotive steel to entrench themselves in the auto segment and several have roped in foreign partners for the high-technology products needed.

Main target of all auto manufacturers is to reduce the weight of car by using lighter but stronger steel which resulted in development of Advanced High Strength Steel (AHSS). AHSS are complex, sophisticated materials, with carefully selected chemical compositions and multiphase microstructures resulting from precisely controlled heating and cooling processes. Various strengthening mechanisms are employed to achieve a range of strength, ductility, toughness, and fatigue properties. These steels are not the mild steels of yesterday - rather they are uniquely light weight and engineered to meet the challenges of today's vehicles for stringent safety regulations, emissions reduction, solid performance, at affordable costs.

The metallurgy and processing of AHSS grades are somewhat different from the conventional steels. All AHSS are generally produced by precisely controlling the cooling rate from austenite or austenite plus ferrite phase. This is done either on the run out table of the Hot Strip Mill (for HRC) or in the cooling section of Continuous Annealing Furnaces of CAL/CGL for cold rolled or zinc coated products.

In this paper we will briefly discuss about the cooling models developed by Danieli for the Laminar Cooling Section of Hot Strip Mills to produce AHSS grades like Dual Phase (DP), Transformation-Induced Plasticity (TRIP) and Martensitic (MS) steels.

Keywords: Advanced High Strength Steel, Automotive Steel, Cooling Model, Laminar Cooling

INTRODUCTION

During 1886 the first petrol or gasoline powered automobile was invented by Karl Benz. This is also considered to be the first "production" of passenger vehicle. For many decades, the United States of America led the world in total automobile production.

In 1929 before the great depression, the world had 32,028,500 automobiles in use and the U.S. automobile industry produced over 90% of them. After World War II, the U.S. retained market leadership with 75 percent of world's auto production. But in 1980, the U.S. was overtaken by Japan but U.S. regained its leadership again in 1994.

In 2006, Japan narrowly passed the U.S. in production and held this rank until 2009, when China took the top spot with production of 13.8 million units. With 19.3 million units manufactured in 2012, China almost doubled the U.S. production of 10.3 million units while Japan was in third place with 9.9 million units. At the turn of the 20th century electrically powered automobiles appeared but only occupied a niche market.

Global production of motor vehicles (cars & commercial vehicles) is 89,747,430 units in 2014 and with an average growth rate of 3%, the estimated global motor vehicle production will be approximately 108 million units during 2020.

The majority of India's car manufacturing industry is evenly divided into three "clusters" – Southern cluster around Chennai, Western Cluster near Mumbai, Pune and Northern cluster in Goregaon, Mannesar, etc.

Southern cluster is the largest with a 35% revenue share, accounting for 60% of the country's automotive exports and home of the India operations of Ford, Hyundai, Renault, Mitsubishi, Nissan, BMW, Hindustan Motors, Daimler, Caparo, Mini, and Datsun.

Western cluster near Mumbai along the Chakan corridor near Pune has a 33% share of the market. Audi, Volkswagen, and Skoda are located in Aurangabad while Mahindra & Mahindra has a SUV and engine assembly plant at Nashik. General Motors, Tata Motors, Mercedes Benz, Land Rover, Jaguar Cars, Fiat, and Force Motors have assembly plants in this area.

Then the northern cluster is around the National Capital Region, and contributes 32%. Gurgaon and Manesar, in Haryana, are where the country's largest car manufacturer, Maruti Suzuki, is based.

An emerging cluster is the state of Gujarat, with a manufacturing facility of General Motors in Halol, and a facility for Tata Nano at their plant in Sanand. Ford, Maruti Suzuki, and Peugeot-Citroen plants are also planned for Gujarat.

Kolkata with Hindustan Motors, Noida with Honda, and Bangalore with Toyota are other automotive manufacturing regions around the country.

India's passenger car and commercial vehicle manufacturing industry overtook Brazil in 2011 to become the sixth largest in the world. From the 3,880,938 motor vehicle units produced in India during the year 2013, we can expect 8 million units production in 2020.

On an average a car uses almost 650-700kgs of finished steel which comes from 900kgs of raw steel and these 8 million motor vehicles will require about 7.2 million tons of automotive grades steel by 2020.

With a conservative average growth of about 10-12%, India is definitely one of the fastest-growing automotive markets in the world. The major automotive steel producers in India are Tata Steel, JSW and POSCO with Bhushan Steel supplying some quantities to car manufacturers located in Northern India. SAIL and ArcelorMittal are planning for a 1.5mtpy plant which may start production in 2019-20. But there is lot more space for new plants to come up to meet the demand of 7 million tons in 2020. Top steel companies are, therefore, increasing their automotive steel manufacturing capacity to entrench themselves in the auto segment and several have roped in foreign partners for the high-technology products needed.

AUTOMOTIVE STEEL GRADES

Today and in the future, automotive manufacturers must reduce the overall weight of their cars. The most cost effective way to do this is to use steel with very high strength to weight ratio. When selecting a material for a particular application, engineers / designers must be confident that it will be suitable for the loading conditions and environment it will experience during service. An understanding of the properties of materials is therefore essential. Fig -1 shows the latest and most modern automotive steel which is AHSS or Advanced High Strength Steel.

Use of AHSS along with other alternative materials, such as aluminum, magnesium and carbon fiber, is expected to increase significantly in vehicle parts. However, vehicle manufacturers will also need to look at the applicability of various materials to different parts of the car. This is required to achieve a balance between light weight and costs. Significant weight reduction benefits of carbon fiber needs to be balanced with associated rise in costs. Different parts of a vehicle also require different materials and vehicle manufacturers will have to assess how they can reduce weight on a part-by-part basis. For this purpose several vehicle manufacturers are working with steelmakers to develop AHSS to enable them to meet the requirement of lighter but stronger cars with the emission reduction targets.

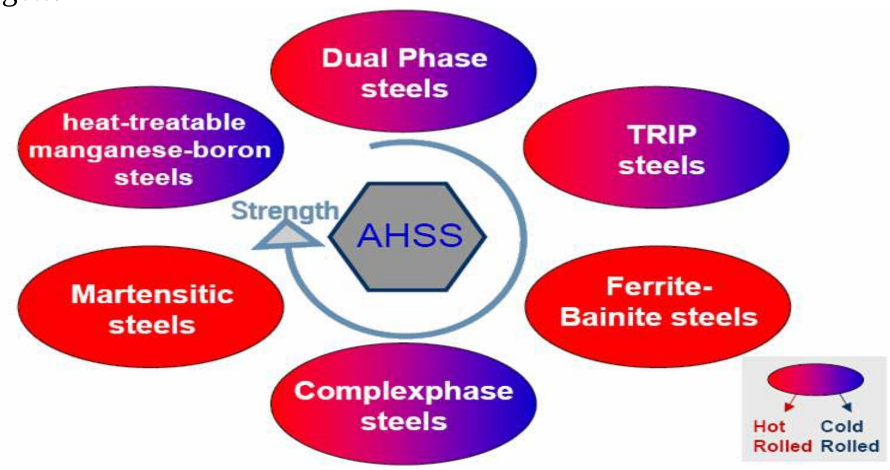


Fig 1 Family of Advanced High Strength Steel (AHSS)

ADVANCED HIGH STRENGTH STEELS (AHSS)

The term AHSS is generally used for dual phase steels, complex phase steels, TRIP steels and martensic steels. It primarily stands for multi-phased steels. The high yield strength micro-alloyed steels also belong to the AHSS group. Conventional high strength steels are single phase ferritic steels. Automotive steels are classified in 3 designations: (1) metallurgical designation includes low strength steels, (2) conventional high strength steels and the (3) AHSS.

The Advanced High Strength Steels (AHSS) have 2 very specific properties – (1) very high mechanical property (Yield Strength between 300mpa & 1000 MPa and Ultimate Tensile Strength between 450 MPa & 1500 MPa) and (2) specific micro-structure consisting of a fine dispersion of hard martensic and/or bainitique particles in a soft ferrite matrix.

AHSS are mainly identified into six categories: (1) Dual Phase or DP steel, (2) Transformation-Induced Plasticity or TRIP steel, (3) Complex Phase or CP steel, (4) Martensitic or MS steel, (5) Ferritic Bainitic or FB steel and (6) Twin-Induced Plasticity or TWIP steel.

Use of AHSS will solve the two most important requirements for the automotive industry. The first requirement of high strength with excellent formability & crash energy absorption can be better fulfilled by DP and TRIP grades than HSLA steel. The second is to extend the availability of steel in strength ranges above HSLA and this area is covered by CP and MS grades.

Before going into production process for these automotive steels, let us briefly be acquainted with their main characteristics.

High-strength low-alloy (HSLA) steels

This group of steels is strengthened primarily by micro-alloying elements contributing to fine carbide precipitation and grain-size refinement resulting in high strength with low alloy content. It enhances weldability and choice of coating, as these steels exhibit neither weld zone softening nor grain coarsening. HSLA grades are particularly suitable for structural components such as suspension system, chassis and other reinforcement parts for the cars.

Interstitial-free (IF) steels (Low strength and high strength)

IF steels have ultra-low carbon levels designed for low yield strengths and high work hardening exponents. These steels are designed to have more stretch ability than mild steels. Some grades of IF steels are strengthened by a combination of elements for solid solution, precipitation of carbides and/or nitrides, and grain refinement. Another common element added to increase strength is phosphorous (a solid solution strengthener). The higher strength grades of IF steel type are widely used for both structural and closure automotive applications. Performance data have shown a significant increase in deep drawability for this steel over drawing quality aluminum-killed steel. Breakage rates in difficult deep drawn parts have been reduced, often dramatically. One or more anneals between draws have been eliminated and better finished parts have been formed.

Laboratory research trials have shown that one or more drawing steps of a multistage draw can be eliminated in a complex part.

Bake hardenable (BH) steel

BH steels have a basic ferritic microstructure and are strengthened primarily by solid solution strengthening. A unique feature of these steels is the chemistry and processing designed to keep carbon in solution during steelmaking and then allowing this carbon to come out of solution during paint baking. This increases the yield strength of the formed part. The composition and processing of these steels are designed to ensure a significant increase in yield strength during low temperature heat treatment particularly paint curing. BH steels are used for visible (doors, hood, tail gate, front wing, roof) and structural (underbody, reinforcement, cross member, lining) automotive parts.

Dual-phase (DP) steel

DP steels are one of the important new advanced high strength steel (AHSS) products for automotive applications. The micro-structures of DP steels typically consist of a soft ferrite phase with disperse islands of a hard martensite phase. The martensite phase is substantially stronger that the ferrite phase. DP steels allow the products to provide high strength, excellent formability and high stain energy absorption capabilities. With careful selection DP steels can be joined by all current welding processes including resistance spot, resistance seam, arc and laser welding methods.

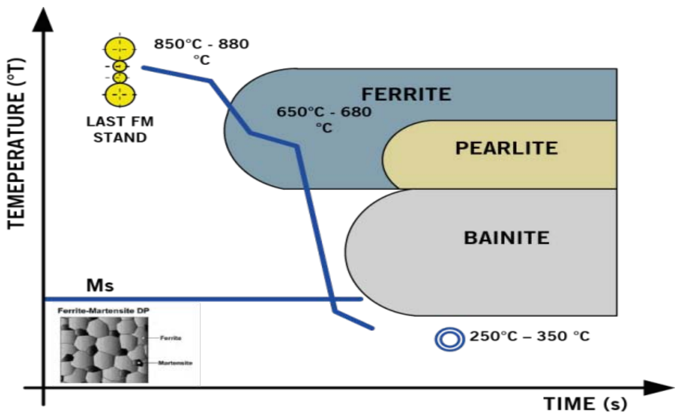


Fig 2 Cooling curve for Dual Phase (DP) steel

Due to the above characteristics, DP steels are often used for automotive body panels, wheel and bumpers.

TRIP (Transformation Induced Plasticity) steel

TRIP steel is a high-strength steel typically used in the automotive industry. TRIP stands for "Transformation Induced Plasticity." It is known for its outstanding combination of Strength and Ductility. TRIP steels use higher quantities of carbon than Dual Phase steels to obtain sufficient carbon content for stabilizing the retained austenite phase to below ambient temperature. Higher contents of silicon and/or aluminum accelerate the ferrite/bainite formation. They are also added to avoid formation of carbide in the bainite region.

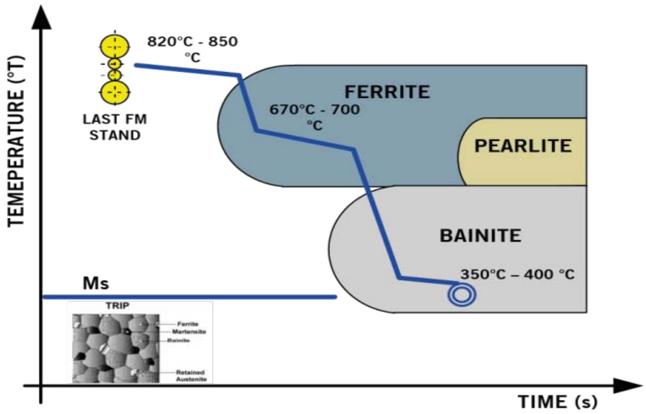


Fig 3 Cooling curve for TRIP steel

As a result of their high energy absorption capacity and fatigue strength, TRIP steels are particularly well suited for automotive structural and safety parts such as cross members, longitudinal beams, B-pillar reinforcements, sills and bumper reinforcements.

The most common TRIP range of steels comprises 2 cold rolled grades in both uncoated and coated formats (TRIP 690 and TRIP 780) and one hot rolled grade (TRIP 780), identified by their minimum tensile strength expressed in MPa.

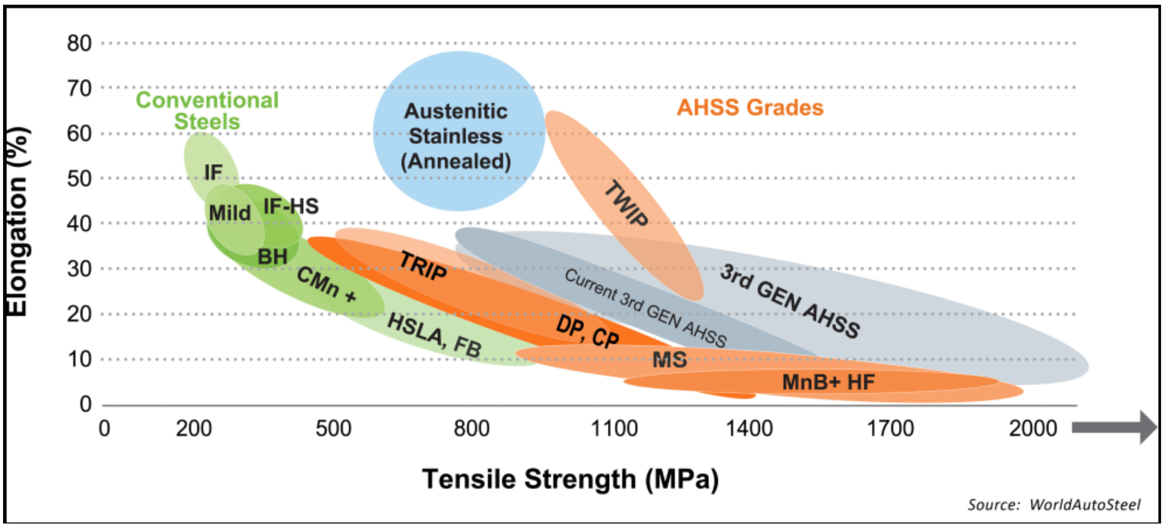


Fig 4 Tensile Strength vs. Elongation foe automotive steels

Complex Phase (CP) steel

CP steels typify the transition to steel with very high ultimate tensile strengths. The microstructure of CP steels contains small amounts of martensite, retained austenite and pearlite within the ferrite/bainite matrix. In comparison to DP steels, CP steels show significantly higher yield strengths at equal tensile strengths of 800 MPa and greater. CP steels are characterized by high energy absorption, high residual deformation capacity and good hole expansion.

Martensitic (MS) steel

To create MS steels, the austenite that exists during hot-rolling or annealing is transformed almost entirely to martensite during quenching on the run-out table or in the cooling section of the continuous annealing line. The MS steels are characterized by a martensitic matrix containing small amounts of ferrite and/or bainite. Within the group of multiphase steels, MS steels show the highest tensile strength level. This structure also can be developed with post-forming heat treatment. MS steels provide the highest strengths, up to 1700 MPa ultimate tensile strength. MS steels are often subjected to post-quench tempering to improve ductility, and can provide adequate formability even at extremely high strengths.

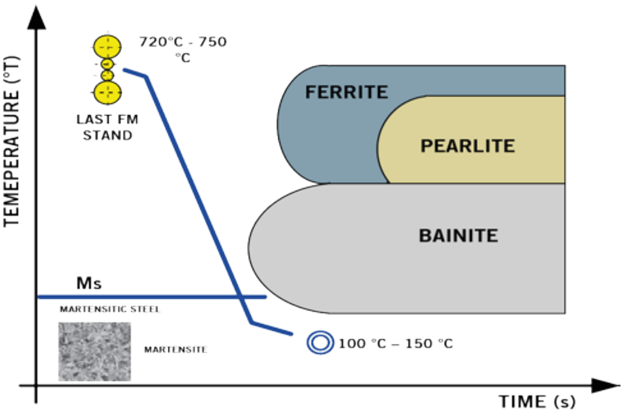


Fig 5 Cooling Curve for Martensitic (MS) steel

Feritic Bainitic (FB) steel

FB steels have a microstructure of fine ferrite and bainite. Strengthening is obtained by both grain refinement and second phase hardening with bainite. The primary advantage of FB steels over HSLA and DP steels is the improved stretchability of sheared edges as measured by the hole expansion test. Compared to HSLA steels with the same level of strength, FB steels also have a higher strain hardening exponent and increased total elongation. Because of their good weldability, FB steels are considered for tailored blank applications. These steels also are characterized by both good crash performances and good fatigue properties.

Twining-Induced Plasticity (TWIP) steel

TWIP steels have high manganese content (17-24%) that causes the steel to be fully austenitic at room temperatures. A large amount of deformation is driven by the formation of deformation twins. This deformation mode leads to the naming of this steel class. The twinning causes a high value of the instantaneous hardening rate as the microstructure becomes finer and finer. The resultant twin boundaries act like grain boundaries and strengthen the steel. TWIP steels combine extremely high strength with extremely high stretchability. The tensile strength is higher than 1000 MPa.

AHSS HRC production for automotive applications

The mechanical properties of steel can be carefully controlled through the selection of an appropriate chemical composition, processing and heat treatment, which lead to its final microstructure. The metallurgy and processing of AHSS grades are somewhat different from the conventional steels. All AHSS are generally produced by precisely controlling the cooling rate from austenite or austenite plus ferrite phase. This is done either on the run out table of the Hot Strip Mill (for HRC) or in the cooling section of Continuous Annealing Furnaces of CAL/CGL for cold rolled/metal coated products.

Here we will briefly discuss about Danieli Advanced Cooling System (Q-Flow+) for the HSM and how it can help to achieve desired mechanical properties and good strip in Hot Strip Mill. We all know that to achieve desired mechanical properties and good physical shape of hot rolled strip, a well designed and efficient Run out table and laminar cooling system is essential.

Fig 6 Water Wall Plus Strip Cooling System

The achievement of precise coiling temperature values is most important in order obtain desired grain growth of steel which would bring required mechanical characteristics. Danieli offers Waterwall type, U-Tube type and Intensive Cooling type on run out cooling system with water banks on the top and multiple nozzles on the bottom. In coactions with a highly efficient cooling model, the laminar cooling system arranged in this area ensures the desired coiling temperature as well as cooling according to preselected cooling strategies to achieve the desired mechanical properties of the rolled strip.

According with the process requirements and final mechanical proprieties to be achieved based on the steel grade product mix, Danieli offers different technical solutions, as follow:

- Water Wall Plus
- Specialized “U” Tubes
- Intensive Cooling

All the above strip cooling systems guarantee:

- Superior control of the requested cooling pattern
- Superior mechanical properties
- High reliability
- Less maintenance and operating costs

Fig 7 Specialized U-tubes type Strip Cooling Solution

The laminar cooling section is divided in main zones and trimming zones. It is especially suitable for the production of DP and multi phase steel strips; the special cooling control allows reduction of alloying additions and therefore cost savings. In comparison to the amount of water of the main zone, the water flow rate in per trimming zone can be recuced to half (end of the laminar strip cooling system for tuning of the properties). The possibility of flow rate control in each header ensures location and division into main and trimming zone.

Water wall plus type laminar cooling system comes with a compact design and simple overall installation. Water wall type cooling headers are designed swinging type with hydraulic cylinders. When ever there is a emergency or maintenance each of the cooling headers can be tilted up making the run out roller table clear from top. Edge masking facility can be also provided on the headers and can be actuated when desired.

Fig 8 Intensive Cooling System

U-Tube type cooling ensures water flow rate distributed over a wide area of running strip, so achieving uniform cooling. Apart from the high cooling power the system is characterised by its flexibility. It will have two power zones : one set of 3 units at system entry and one set of 5 units towards the end of Runout table to created different cooling stretegy.

The specialized U-tube laminar system consists of three types of cooling header banks. Power cooling banks are designed to deliver maximum quantity of water in a short distance to achieve a deep temperature drop at the beeging of cooling zone. Same cooling header pattern was implemented by Danieli at the Baosteel Meishan HSM which ensre high degree of flexibility with a modern and extended U-tube type Laminar Cooling System which has a total length of more than 100 meters with available instantenous water flow rates of almost 16,000m3/h.

Apart from normal laminar cooling systems, Danieli can offer a 'specialized' system for the production of high value added steel grades like Dual phase (DP) and Transformation Induced Plasticity (TRIP) steel, where target cooling temperatures can be below 300 - 200 degrees. In such cases the total temperature drop required will go above 500 degrees a really strong cooling system is a must.

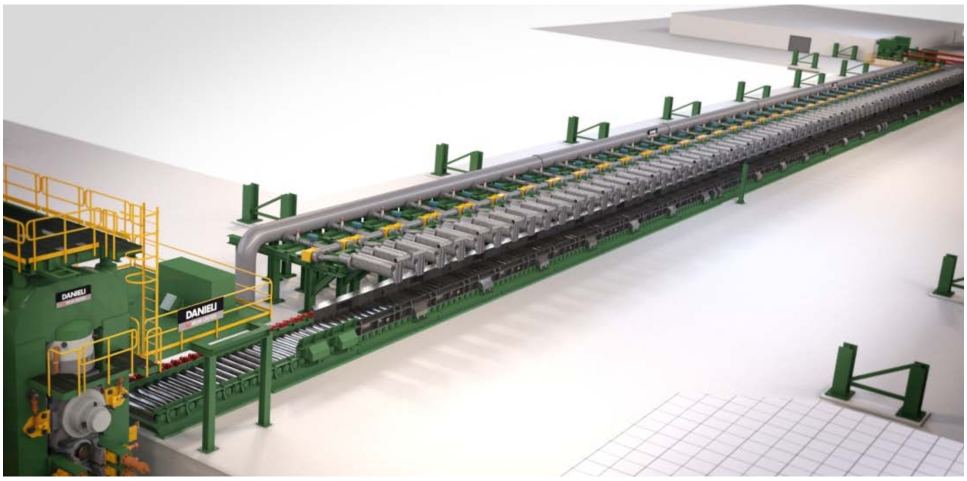


Fig 9 Danieli Laminar Cooling System

Danieli Wean United developed a new cooling system unit, Intensive Cooling System that is able to drastically reduce the strip temperature in the first part of the run out table controlling the passage from the austenite or austenite plus ferrite phase in the strip. The efficiency of Danieli's intensive cooling system and its compact layout thus make it possible to realize a cooling system able to perform the required heat treatment in a run out table, with a shorten length available (with length comparable to a non Dual Phase production model), without affecting investment costs.

OUTLOOK AND CONCLUSION

The growing competitiveness amongst car manufactures in India mainly revolves around two major factors – to maximize fuel efficiency and minimize carbon dioxide emmissions. The industry is exploring various options to increase fuel efficience and the most important factor in this respect is to reduce the weight of the cars. Such effort to design vehicles with lowest weights is increasing the use of alternative materials like aluminium and fibre reinforced plastics.

The use of steel in car manufacture accounts for almost 68% of its weight. To retain this position and to improve upon it, development and use of AHSS (Advanced High Strength Steel) have a major role to play. For car ,manufacturing AHSS provides a perfect balance on a cost-weight-strength basis, despite the increasing use of aluminum and carbon reinforced fibre polymer (CRFP).

With the liberalization of industrial policy and other initiatives taken by Govt. of India, the steel producers in the country must concentrate on production and marketing of AHSS to sustain the fierce competition from overseas steel producers.

Strip Processing for Automotive Qualities

M. Cottin[1], C. Sasse[1] & Rajesh Garg[2]
[1]SMS Group, Germany
[2]SMS India Pvt. Ltd., Gurgaon-122016, India
Email: rajesh.garg@in.sms-siemag.com

Steel continues to be the most important material for the automotive industry, whereby particularly the share of high-strength steels is constantly increasing. At the same time steel is also in extreme competition with other materials for automotive applications. As manufacturers are required to build light and fuel efficient vehicles, many new steel grades with optimized combinations of the properties have been developed. Multi-phase steels are increasingly being used for car components. These high-strength but easily deformable steels must meet the highest quality requirements to be used in automobiles.

Hence Strip Processing Lines for the production of high-quality strips for use in interior and exterior components must be set up to produce high material strengths and flawless surfaces. In the lines, account is taken of the stringent demands on surface quality. This commences with cleaning, which is followed by surface-friendly annealing, and high-grade coating technologies for the application of a zinc layer, passivation for preserving oils. Advanced annealing and cooling strategies are implemented together with skin-pass mills in order to achieve outstanding material strengths.

A high yield of high-quality strips is necessary for the economic efficiency for the facilities. Another important criterion is that the plants are highly flexible, so that the product range can be adapted to changing market situations. This is possible using so-called multi-purpose lines, which can be used either as hot-dip galvanizing lines or as annealing lines, and offer various options for the strip cooling. In a number of projects, SMS group has already proven itself to be the right partner when it comes to the conception, design, construction and commissioning of automotive and multi-purpose lines.

This paper illustrates the most important process steps and economic solutions regarding the production of steels for use in automobiles. In addition, the various line concepts and references are presented.

Keywords: Cold Strips, Automotive, Galvanizing, Annealing, High-Strength Steel Grades, Martensitic Grades, Dual-Phase Grades

INTRODUCTION

Steel remains the key material in automotive manufacturing, with the proportion of high-strength steels continuously rising in fierce competition with other materials (plastic, aluminum). Parallel to this there is pressure on manufacturers to build lightweight, low-consumption vehicles, prompting the development of many new steel grades with optimized property mixes. Much favored here are more and more multiphase grades that combine high strength with high ductility. Both super-strong and easy to form, these steels need to meet top standards for use in motor vehicles. That applies to both material and surface quality.

Seeing that the automotive industry is the most important market and driver of new technology, steel producers must fulfill these requirements. Therefore, it is vital that strip processing lines for manufacturing valuable steel plate for internal and external parts (usually hot-dip galvanizing and annealing lines) are engineered to produce high-strength materials with flawless surfaces.

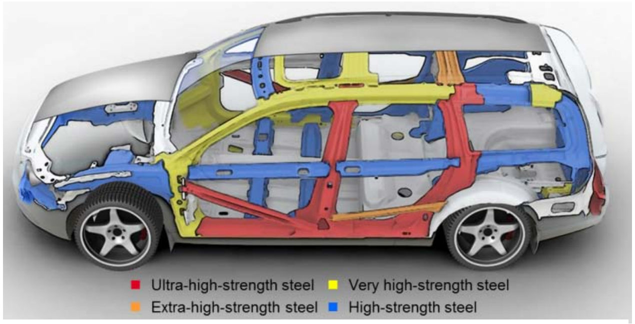


Fig 1 In some applications weight savings of up to 40% are possible with modern high-strength steels

Plants equipped for surface quality start with systems for cleaning and continue with surface-friendly annealing, zinc coating technologies, passivation, and preserving-oil application machines. Crucial for excellent material strength are sophisticated annealing and cooling strategies as well as skin-pass mills for optimal post-treatment.

Another aspect is cost-effectiveness ensured by high yields of steel strip in the right quality. That takes fast production rates, large capacities and steep start-up curves for stable, reproducible production of all steel types, including automotive grades. High production plant flexibility is a further decisive criterion for adjusting the product range to changing market demands. This is possible, for example, with multipurpose lines that can be used either as hot-dip galvanizing or annealing lines with various strip cooling options.

SYSTEM SUPPLIER

SMS group is the only company worldwide capable of meeting all these demands with the corresponding solutions. That's because all products and services are available within the SMS group – from mechanical and process-technology components through furnaces and air knife systems to electrics and automation, control and measuring systems, and all the associated know-how. Drawing on the combined strength of the renowned companies and brands within the SMS group, the lines are supplied from a single source as a system supply:

- DREVER (Furnace technology)
- DUMA-BANDZINK (Air-knives & oiling machines)
- ELOTHERM (Induction furnaces)
- FOEN (Air-knives & strip stabilization)
- IAS (Zinc pots)
- MET/Con (Process know-how)

Proof of SMS group's competence in the planning, design/engineering, erection, and commissioning of automotive lines is provided by a whole host of successful projects. Specifically, since 2000, SMS group has attracted 36 orders for automotive lines (as of

2014). This goes to show that leading steel manufacturers on all the major markets trust in the expertise, capacity, and knowhow of SMS group.

Fig 2 SMS group is capable to deliver complete strip processing lines as a system supplier

LINE CONCEPTS – MULTI PURPOSE LINES

In addition to modern hot-dip galvanizing lines and continuous annealing lines for high quality strip and high capacities, the product portfolio includes many other line concepts. More than ever, cost-effectiveness and flexibility are the main demands manufacturers make on strip processing lines. These two aspects are profoundly interdependent in a constantly changing market environment. Flexible production conditions ensure a reaction to changing demands with the greatest possible efficiency. This is where automotive lines from the SMS group stand out because of their extreme flexibility due to the highly developed, tried-and-tested technologies and components. Universal cold strip lines that offer different processes for the strip depending on current requirements provide even more flexibility.

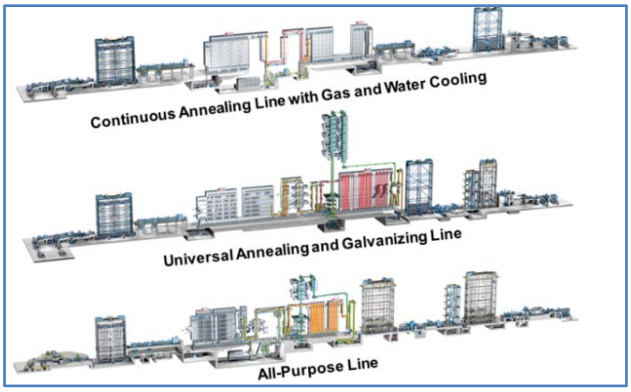


Fig 3 Besides modern hot-dip galvanizing and continuous annealing lines, SMS group offers some flexible multi-purpose line concepts

Universal annealing line with rapid cooling and water-spray cooling:

Apart from a gas powered rapid cooling section, this type of line comes optionally with a water-spray cooling system. In this way the line features two options of strip cooling which can be used for different products

Universal annealing and hot-dip galvanizing line:

It is a special type of line in which the cold-strip first goes through recrystallization annealing and then moves on to either a zinc bath or an over aging zone. In this way the flexible line produces two different product groups (annealed and galvanized) in extremely high quality.

All-purpose line:

To create maximum versatility, this line type features four different process routes. Following slow cooling, the steel strip can run through one or more of these routes. The line comes with two cooling systems (gas and water cooling) as well as a galvanization option. Furthermore, annealed materials can be re-heated in an over aging or tempering zone.

Furnace Technology:

A very important and quality-decisive part in cold strip processing is the furnace technology, in particular the cooling technology and the furnace control.

Annealing curves:

A comparison of typical annealing curves for different high-strength steels shows that cold-strip processing furnaces must offer considerable flexibility with regard to heat treatment. Equipped with various cooling systems the processing furnaces of SMS group are capable to produce the latest high-strength steel grades for the automotive industry. That allows for lighter and fuel-saving vehicles.

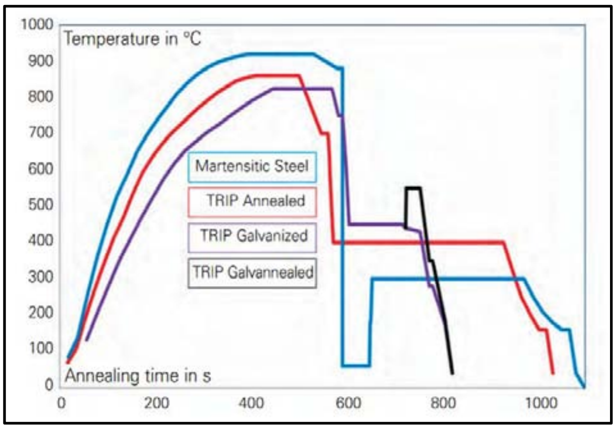


Fig 5 Comparison of different cooling curves for the production of modern high-strength steel grades

Pre-oxidation chamber:

During the heat-up process of high alloyed steel grades in the galvanizing furnace, manganese and silicon oxides appear on the surface of the strip. The oxides have a very low wettability causing quality problems during the hot-dip galvanizing process. With the pre-oxidation technology the dew point is altered in the pre-oxidation chamber. This effect causes the strip surface – including the areas of the manganese and silicon oxides – to be covered by an iron layer which has the required wettability.

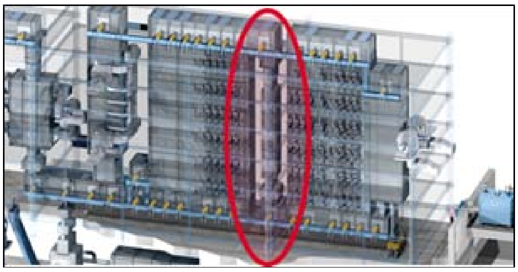


Fig 6 A vertical pre-oxidation chamber increases the wettability of high-alloyed high-strength steel grades

Ultra-fast cooling:

High strength steel grades (e.g. TRIP and DP grades with tensile strengths up to 980 MPa) can be produced either by using large amounts of expensive alloying elements or by application of high cooling rates. When applying high cooling rates, conventional systems consume a lot of resources. With the ultra-fast cooling system, cooling rates of up to 150 kelvin per second per millimeter can be achieved due to the injection of pure hydrogen into the fast cooling chamber (up to 50% hydrogen content) limiting the diffusion of hydrogen into the adjacent chambers (patented). Regarding combustion gas, electrical energy, hydrogen and nitrogen savings of up to 3.5 million Euros per year are possible, without considering the savings due to reduced consumption of alloying elements. (Based on: Capacity 1,000,000 t/year, Coal equivalent natural gas: 65 €/t, Electricity: 0.07 €/kWh, H_2:0.6 €/Nm³, N_2:0.045 €/Nm³ (Source: Shougang Daily 2009)

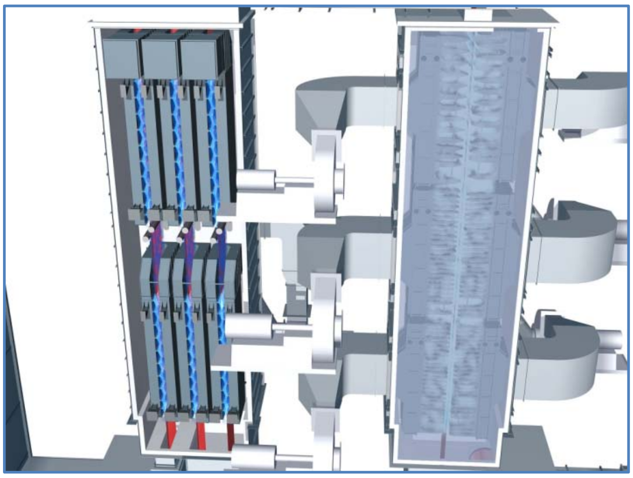


Fig 7 Ultra-fast cooling serves for the production of high-strength steel grades with high cooling rates

Water-spray cooling:

For higher cooling rates, the water-spray cooling system involves immersing the strip in demineralized water while special nozzles spray on the strip from both sides at high pressure. Here, the cooling rate is more than 1,000 kelvin per second per millimeter strip thickness, sufficient for manufacturing dual and complex-phase as well as martensitic grades with tensile strengths of upto 1,700 megapascal.

Fig 8 Water-spray cooling for producing steel grades with tensile strengths of up to 1,700 mega Pascal

I-Furnace:

During heat treatment, microstructure is precisely adjusted to meet requirements regarding strength and formability. Precise and efficient heating and cooling processes are guaranteed by a new mathematical/physical furnace model and an annealing microstructure model. In combination with the non-contact IMPOC® online measuring system for tensile and yield strength, this is a great step forward towards an autonomous working furnace.

Special sophisticated grades can be produced more easily and homogenous material characteristics over the whole coil length can be achieved. A capacity increase up to 15 percent is possible due to a better utilization of the furnace capacity as well as an efficient production planning and transition behavior. Also energy savings can be realized due to a better temperature control close to its lower limit (in average -10 K).

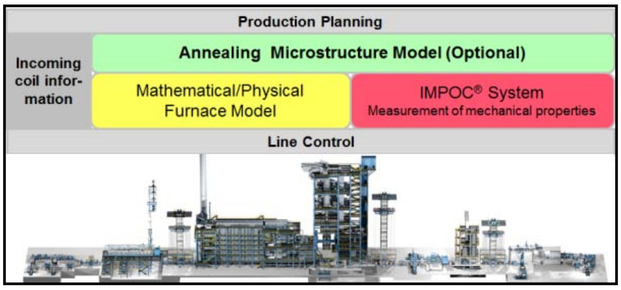


Fig 9 Set-up of the I-Furnace

Galvanizing Section

As an outstanding feature, hot-dip galvanizing lines for automotive exposed applications are capable of producing best surfaces (C-surfaces). What mainly determines excellent surface quality is an outstanding air knife system. Also significant here is zinc pot equipment tailored to the special requirements of the process as well as an electromagnetic strip stabilizing system that guarantees smooth strip travel and superb coating precision.

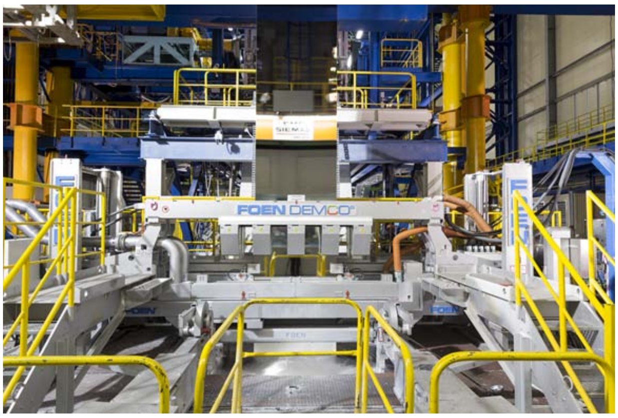


Fig 10 The production of C-surface qualities for automotive exposed applications is a stand-out feature of the SMS group's galvanizing technology

A key quality characteristic is the accuracy of the coating thickness. Complying with narrow coating tolerances also means zinc savings and cutting of production costs. For example 400 tons zinc per year can be saved due to a stable strip run with a stabilization system. Furthermore, savings of 550 tons of steel strip per year can be realized due to yield increase (no losses due to cut-outs after thickness changes). This adds up to a total saving of more than 1 million Euros per year.

Based on: Zinc saving: 2 g/m², Strip width: 1500 mm, Strip thickness: 1.0 mm, Strip speed: 160 m/min, Production hours: 7,000 per year, zinc: 1,500 €/t, layer thickness change: every 15 hours, cut-out: 100 m, galvanized steel: 800 €/t

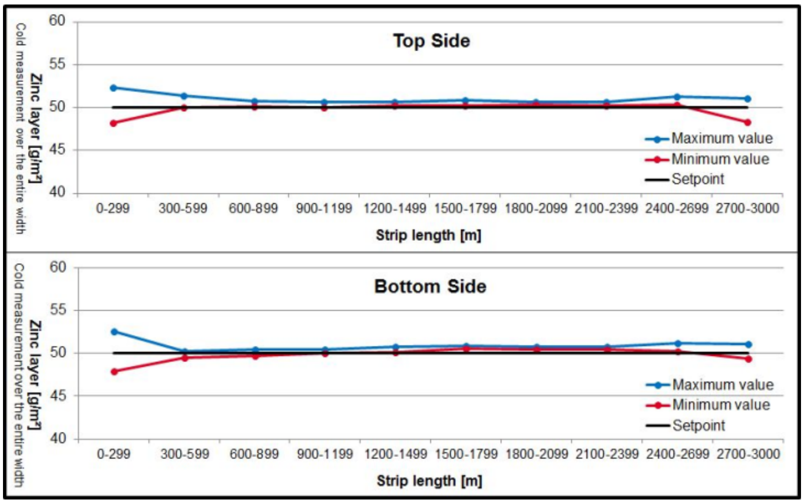


Fig 11 The production of C-surface qualities for automotive exposed applications is a distinguishing feature of the SMS group's galvanizing technology

The zinc pot and zinc pot exchange system is responsible for the flexibility in regards to different coatings. In addition, a special refractory lining is required for modern coatings with high aluminum and/or magnesium contents. Due to the close collaboration with refractory providers, the required know-how for the manufacturing of these specialized zinc pots is available. Another advantage is the high quality assurance provided by the broad manufacturing range (e.g. own inductor and switch gears as well as control systems).

PROCESS KNOW-HOW

In order to increase the production of high-quality material and to fulfill the growing expectations of the automotive industry, steelmakers must have wide-ranging know-how in terms of plant technology, operation, processes, quality control and, last but not least, know-how for automotive exposed and advanced high-strength steel grades including certification and approval procedures.

The know-how consulting service is highly focused on the production of coated and uncoated grades for automotive applications covering IF and BH as well as multi-phase steel grades. Among other things the following know-how and technology packages are offered:

- Equipment, process and organization evaluation (fact finding workshops)
- Startup assistance
- Continuous production assistance and process optimization
    - Quality control (defect analysis and counter measurements)
    - Improvement of yield and cost structure
    - Extension of product portfolio
- Hands-on training
- Grade books (Process and operation parameters of complete production route)
- Certification and approval assistance

REFERENCE SITUATION

Between 2000 and 2015, SMS group received orders for 52 annealing and galvanizing lines for carbon steel from world leading steel producers. 39 of these lines are producing high-quality automotive grades. Some examples are given below.

Magnitogorsk Iron & Steel, Russia

For MMK, SMS group delivered one hot-dip galvanizing line and one universal annealing and hot-dip galvanizing line. The two cold strip lines in the MMK plant in Magnitogorsk, Russia, together produce more than one million tons of high-quality steel strips, especially for automotive outer and interior parts. It's a plant array that covers a very wide range of top-quality materials – from soft to high-strength grades – and produces two different product groups (annealed and galvanized) as required. Both plants went on stream in summer 2012.

Handan Iron & Steel, China

Engineered for an annual capacity of over one million tons, the annealing line at Handan is one of China's largest plants of this type. SMS Group attracted the order in August 2008, and commissioning in September 2010. To achieve this impressive capacity, the line is operated at a speed of up to 450 meters per minute and the maximum strip width is 2,080 millimeters. A special feature is the annealing furnace directly connected to an ultra-fast cooling zone. This cools the strip extremely rapidly yet evenly, while retaining the strip shape and producing very good surfaces.

Shougang Jingtang Iron and Steel, China

Acting as a consortium leader, SMS group built two continuous annealing lines for Shougang Jingtang on the man-made Caofeidian Island in north-east China.

The first line was ordered as recently as in 2007, and started production at the end of 2009. Then the second line, ordered in 2008, went on-stream five months ahead of schedule in December 2010. Together, the plants are designed to process almost two million tons of cold-strip per year from the pickling line/tandem cold mill also supplied by SMS group, with most of this material going to the automotive industry. Both lines achieved a successful production start with an excellent start-up curve.

Hyundai HYSCO, South Korea

The first time Hyundai Hysco partnered with SMS group to erect a universal annealing and hot-dip galvanizing line was in 2005. It was a complex project, involving installation of the necessary components for hot-dip galvanizing in an existing annealing line and the construction of by-passes so that the line could be re-commissioned as a universal annealing and hot-dip galvanizing line in 2006.

Then, in 2012, Hyundai Hysco again ordered another universal annealing and hot-dip galvanizing line and a pure hot-dip galvanizing line from SMS group for its cold rolling complex in Dangjin, South Korea. Both lines successfully went into production in April

2013 and have since then been producing high-strength steels for Korean automotive manufacturers including Hyundai motors and KIA.

Fig 12 Steel strip from Hyundai HYSCO is supplied to customers including Hyundai Motors and KIA

PRO-TEC Coating Company, USA

PRO-TEC successfully commissioned a new continuous annealing line for the production of cold-rolled ultra-high strength steel coils. The line was supplied by SMS group and is located in Leipsic, Ohio. In February 2013, the first sellable prime coil was produced.

Each year, 500,000 short tons of steel strips for automotive structural components for cars, trucks and sport utility vehicles can be produced, with a view to both improve the safety of vehicles and reduce their weight. The annealing process and special high cooling rates, along with tempering, reduce the strain hardening in the material caused by the rolling process and enable the high-grade metallurgical properties to be attained.

Among other sophisticated technologies, the line features a high-capacity furnace with an integrated ultra-fast cooling system and a water-spray cooling system for particularly high cooling rates, which allow the manufacturing of fully martensitic grades and ultra-high-strength multiphase steels.

Fig 13 The ultra-high-strength steels produced in the PRO-TEC annealing line are mainly used for manufacturing crash-resistant major components in the passenger cell.

CONCLUSION

The paper outlines that SMS group delivers efficient and innovative equipment for cold-strip processing lines all from one single source. Some new developments ensure that SMS' customers are capable to produce modern steel grades including high-strength steel grades. At the same time the integrated technologies keep the operation costs low. Furthermore, very flexible plant concepts are available. In a market environment that varies continuously flexible production conditions, make it possible to always react to changes in demand with the aim of achieving maximum cost efficiency. Last but not least, SMS group has proven its ability to design, deliver and commission these technologies several times. The majority of market-leading automotive steel producers rely on SMS group's technology.

Cold Mill Complexes for Automotive Production

Djumlija Gerlinde & Dr. Finstermann Gerhard
Siemens VAI Metals Technologies GmbH
Email: gerlinde.djumlija@primetals.com

The paper gives an insight on important questions for building cold mill complexes and is explaining different references from Europe and Asia - from small capacities up to high end automotive facilities.

Building a new cold mill complex on a green field is a big challenge. The project starts long before the actual construction and installation on site. The planning phase is based on detailed know-how about the market as well the cold rolling process and all requirements alongside, such as e.g. the correct location, access to energy, fluids, logistic ports etc. Siemens VAI with its global set-up and large pool of specialists contributes to clarifying open questions and supports in developing the right concept for the cold mill complex - based upon the final product mix given by the requirements of the target market and customers, their required capacity, product quality and type of steel grades. Siemens VAI supplies tandem cold mills, reversing mills, skin-pass mills, strip processing lines, heat treatment facilities, layout and logistic planning, as well as all related automation and production control (MES) systems and auxiliary facilities (roll shops, storage, finishing lines such as slitting and recoiling lines, and packing and dispatch equipment). New in the portfolio since summer 2012 is also the expertise in acid recovery. Various scenarios which have already been successfully implemented will give you further insight into cold mill complex facilities.

Keywords: Cold Mill Complex, Tandem Cold Mill, Strip Processing Lines, SIROLL SIAS®, SIROLL SmartCrown®

1 INTRODUCTION

All recent cold mill facilities Siemens VAI Metals Technologies built have in common, their strict orientation to highest product quality, and material strength together with high production capacities to meet the market demands for decades to come.

After having installed excellent facilities in Europe with proven capabilities to fulfil or even exceed the original requirements in producing highest quality steel for the automotive market, two major players in China have placed orders with Siemens VAI: Valin ArcelorMittal Automotive Steel Co., Ltd. and Tangshan Iron and Steel Group Co., Ltd. will go on stream within the next 2 years. Both steel producers are focusing on extending their portfolio with advanced high-strength steel grades by building new cold mill complexes.

2 TODAY'S CHALLENGES IN COLD ROLLING & PROCESSING

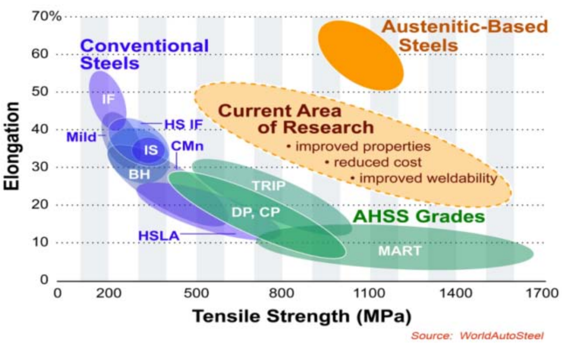
Profitable cold-rolling operations today require flexible production systems to cope with the changing demands of their end users. The rapid development of new steel grades with excellent forming properties with high strength properties become a considerable portion of a typical cold mill product mix.

However, these advanced high-strength steel grades (AHSS) are not the only challenge for the cold rolling process. Some representatives of construction and HSLA grades or the Si grades in general can be regarded as equally delicate with respect to massive forming and joining processes. All these grades can be difficult to subject to welding, scale breaking and side trimming, as well.

For the cold mill in general this means that the operational range in terms of rolling force, rolling torque and drive power is to be widened to allow for a sufficient degree of cold reduction for the entire product mix. This requirement generates higher load collectives for all mechanical components, sometimes already today reaching certain limits. Operating the mill at high load levels also drives the need for a more efficient mechanical actuator system with large working ranges to be able to cover the entire product mix at a minimum of roll inventory and other process consumables.

3 PRODUCT MIX OF COLD MILL COMPLEXES FOR AHSS AND AUTOMOTIVE GRADES

The market volume of HSS for hot and cold rolled strip is determined by the demand of the automotive industry. About 38 % of the consumed flat steel is of HS quality of which 95 % is conventional HSS, 5 % is AHSS.



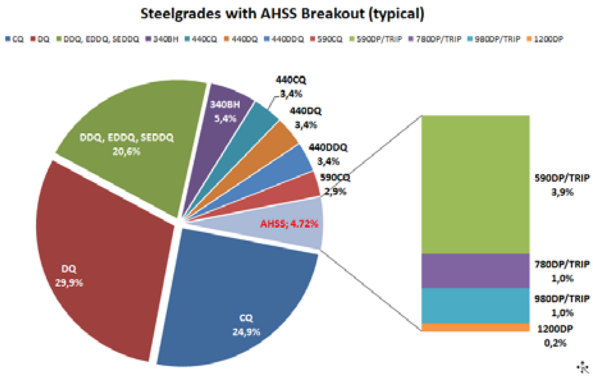


Fig 1 Steel grades market demand[1]   Fig 2 Typical product mix for Cold Mill Complexes

New production facilities for cold strip for automotive applications have to be able to produce AHSS, although the share of AHSS in the product mix is not dominant. Trends in the product mix for Cold Mill Complexes for automotive grades are approaching DP, TRIP, MP grades up to tensile strengths of 1,300 MPa already, which can reach up to 30 % of the product mix.

For automotive steel grades the most suitable combination that is capable to produce this advanced high-strength steel is a combination of PLTCM, CAL and CGL.

4 RECENT COLD MILL COMPLEX PROJECTS

4.1 New PLTCM and special componentsfor automotive steel production: Valin ArcelorMittal Automotive Steel Co., Ltd.

Siemens VAI is supplying a combined pickling line and tandem cold rolling mill to automotive steel producer Valin ArcelorMittal Automotive Steel Co., Ltd. (VAMA) in China. For their new continuous annealing line, continuous galvanizing line and recoiling line Siemens VAI was awarded the supply of 3 light gauge laser welders LW21L. All three lines will be equipped with the online surface quality control SIROLL SIAS.

Start-up of the new pickling line and tandem cold rolling mill is scheduled for mid-2014. In its initial construction stage, the new cold rolling mill is designed for an annual production capacity of 1.5 million tons of steel strip and can be expanded to produce an annual volume of 2 million tons by adding a 2^{nd} payoff reel, a 4^{th} pickling tank and a 5^{th} mill-stand in phase 2. Siemens VAI is supplying the entire mechanical and electrical equipment, all automation and safety systems of the pickling line tandem cold mill.

4.2 Latest state-of-the-art cold mill complex: Tangshan Iron and Steel Group Co., Ltd.

The most recent project awarded to Siemens VAI is the cold mill complex for Tangshan Iron and Steel Group Co., Ltd Part of Tangshan's strategic development plan is the extension of the existing cold rolling and strip processing facilities with the new cold rolling complex no. 2. Tangshan has the clear target to produce highest quality sheet for the automotive industry.

The project comprises a pickling line tandem cold mill (PLTCM), a continuous galvanizing line (CGL) and a continuous annealing line (CAL) and finishing lines. One key element of the new production lines can be found in the highly advanced automation systems being installed on all three major facilities. This will ensure, all three lines will communicate with the superimposed production planning, supervision and control system. Highlights of the pickling line are its high turbulence tunnel type tank design in Polypropylene and a sophisticated acid control and setup system SIROLL FAPLAC®APM to safeguard best pickled surface quality, high productivity and low acid consumptions. The tandem mill will be built in 5-stand, 6-high technology with SIROLL SmartCrown® based intermediate roll shifting systems. Work and intermediate roll bending will complement the flatness actuator systems on all mill stands. Stand no.5 will in addition be equipped with a multi-zone cooling system. Both process lines will be supplied with SELAS furnaces with high efficient jet cooling systems to allow the production of all advanced high strength steels. Special attention is paid on the equipment of both lines for best surface quality to fulfil the automotive requirements.

Key data PLTCM

Mill type	5-stand, 6-high
Annual capacity cold rolled	1,600,000 t
Installed power per stand	6,400 kW
Rolling force	35,000 kN
Rolling speed	max. 1,453 m/min
Steel grades	CQ, DQ, DDQ, EDDQ, SEDDQ, HSS, AHSS

Strip thickness	0.2–2.5 mm
Strip width	700–1,600 mm
Coil weight	max. 26 t

Key data CAL

Annual capacity cold rolled	750,000 t
Process speed	420 m/min
Entry and exit speed	650 m/min
Steel grades	CQ, DQ, DDQ, EDDQ, SED-DQ, HSS, BH, DP, TRIP, MS
Strip thickness	0.2–2.5 mm
Strip width	700–1,600 mm

Key data CGL

Annual capacity cold rolled	420,000 t
Process speed	180 m/min
Entry and exit speed	250 m/min
Steel grades	CQ, DQ, DDQ, EDDQ, SED-DQ, BH, DP, TRIP, HSS
Strip thickness	0.2–2.5 mm
Strip width	700–1,600 mm

5 TECHNOLOGICAL HIGHLIGHTS OF THE NEWEST COLD MILL COMPLEXES

The newest Siemens VAI Cold Mill Complexes are equipped with the latest technological features. Some examples are explained in the following paragraphs.

5.1 Advanced pickling model – SIROLL FAPLAC®APM

For pickling lines the requests are high quality of clean strip surfaces at maximum throughput of the line together with a minimum consumption of acid. The recently developed SIROLL FAPLAC®APM (advanced pickling model) takes a certain number of coils into account of a scheduled production for pre-calculation. Using this system an optimum strip speed, a minimized rate of over-pickling and an optimum balance of utilization in terms of economized resource input can be achieved. SIROLL FAPLAC®APM regulates and controls the basic and process automation in the pickling process section of a pickling line. FAPLAC stands for Fully Automated Pickling Liquor Analysis and Control.

5.2 SIROLL SIAS® - Online surface quality control

In cold rolling mills, SIAS® automatically detects and can classify surface defects visible on the strip such as non-metallic inclusions, blisters, shells or slivers as well as mechanical damages such as roll marks, folds, cracks, holes and scratches. This provides “high resolution” visualization system detects and identifies the required image in real time, with flexibility in adapting inspection parameters to different cases. In processing lines coating defects like dross, streaks, arc spots on tin-plate, and anode marks are identified and classified. Results are displayed and stored in coil reports tracing the defects on every coil. Through the easy implementation of SIAS® and the accurate and reliable data collection of surface quality of the product leaving the line or mill, the process and its impact on the strip's surface will be recorded.

5.3 Automatic flatness control – SIROLL SmartCrown®

The backbone of the SIROLL CM flatness control system is provided by the patented SmartCrown® work and/or intermediate roll contour. This solution features a special roll contour geometry, which offers significant advantages in terms of profile and higher-order shape control. The coefficients are chosen in a way that for any roll shifting positions, the resulting unloaded roll gap profile is always cosine-shaped contour lateral shifting of the bottle-shaped intermediate rolls results in a continuous, gradual adjustment of the roll gap profile.

A special intrinsic feature of SmartCrown® is its ability to control 2nd and 4th order (6th order is also possible, but seldom needed) shape defects by the basic shape set-up of the roll contour and the shifting position of the work or intermediate rolls. This feature allows a drastic reduction of product-dependent, different roll cambers. In actual fact, a rolling mill equipped with SmartCrown® can handle even complex product mixes with only one roll contour used for all rolls in all stands concerned. The SIROLL CM flatness solution package includes all relevant flatness actuators, the flatness measurement systems and the flatness control system itself.

5.4 Off-Gauge Optimizer

Off-gauge strip between production runs causes excess processing costs and lowers facility yield. Leveraging the mill's hidden potential, the SIROLL Off-Gauge Optimizer package significantly cuts reprocessing costs. The package combines technology, process control and instrumentation, and features the smart implementation of the tandem cold mill control algorithm based on the mass-flow principle. In a reference installation at the Voestalpine Stahl continuous tandem cold mill (CTCM) in Linz, Austria, the package proved its efficiency by shortening off gauge lengths by an average of approximately 8 m (the total mean off-gauge length has been decreased from 13.72 m to 5.79 m). This corresponds to a yield increase of 0.25% for a typical product mix, or to an output gain of approximately 4,000 tons per year for an annual production of 1.6 million tons. The investment in the package typically pays for itself in twelve months.

5.5 High performance laser welder

In the last few years the requirements for welders have changed tremendously mainly due to harder steel grades, thinner gauges, perfect welding quality criteria (e.g. weld robustness, over thickness). After the development of Flash Butt and Mash Lap welders, Siemens has developed light and heavy laser welders using a CO_2 laser source. Now Siemens has reached a new step with the integration of an Asolid laser source, replacing the CO2 resonator. The Asolid technology has significant advantages compared to the CO_2 solution. The beam from the laser source to the process heads (cutting and welding) is transmitted through optic fiber instead of mirrors. The welder adjustment becomes easy, the maintenance operations are reduced to almost nothing for the beam path and, thanks to the available fiber length; the laser source can be installed apart from the welder.

5.6 Advanced electrolytic strip cleaning technology

The goal of the cleaning section is to ensure strip cleanliness before strip entering into the furnace. All remaining pollutant can create strip defect or make deposit on roll surface that will make roll pick-up after a certain time and at the end have huge impact in regards of the line production by destroying surface quality. Selected technology for high production automotive sheet for galvanizing and annealing lines is based on electrolytic cleaning section which brings best efficiency in strip cleaning.

5.7 Mechanical properties measurement

The new trend in line production is to be able to have an instantaneous way of checking the mechanical properties thus avoiding to wait too long time by collecting strip samples and getting results from the laboratory. Siemens mechanical properties monitoring system delivers inline analysis to be able to instantly react to the required parameters in view of improving the quality.

6 CONCLUSIONS

Having one single supplier for building a cold mill complex has many advantages. The benefits can be seen on the technological side as well as on the project management side. One single supplier can optimize the production route across the whole cold mill process (interfaces) – based on advanced know-how starting from cold rolling to the final product. The mechanical equipment can be cross standardized and thus requires less spare part logistics during the operation of the complex. This especially applies for the processing lines as well as the consistent and fully integrated cross standardized drive and automation systems. All this leads to a higher performance guarantee due to the overall technical responsibility for the complete cold mill complex. Considering the project management from planning, implementing and coordinating suppliers, local manufacturing and erection companies' one single supplier makes it much easier.

With our worldwide experience we help our customers to meet the ever-increasing quality demands of cold-rolled strip products - especially in providing solutions for producing AHSS and automotive steel grades, as well as the complete supply of turn-key mills comprising mechanical equipment, electrics, basic automation and process optimization, media supply and all related logistic and auxiliary facilities.

References

1) Worldautosteel, http://www.flickr.com/photos/worldautosteel825/sets

2) G. Finstermann, A. Seilinger, G. Nopp, G. Djumlija, Comparison of 4-high and 6-high mill-stand technology in cold-rolling mills, MPT International, volume 1 2007.

Technology Selection for Cold Rolling Mill Complex, Bokaro Steel Plant

PB Neogy & R Khillan
MECON Limited, Ranchi, Jharkhand-834002, India
Email: pbneogy@meconlimited.co.in

Automotive sector accounts for roughly 12% of the overall global steel consumption. Steel is the dominant material in automobile manufacturing, accounting for roughly 60% of the weight of an average automobile. India is estimated to become the world's fourth-largest automobile manufacturing country by 2020, growing from the current 3.5 million units to about seven million units. Considering 650-750 kg of steel is required to produce a unit, the total market size is huge. Unfortunately, India has to rely on imports for auto grade steel. India imported 7.9 mt of steel in the fiscal ended March, 2013 of which auto-grade steel was about 3 mt.

As a part of massive modernisation and expansion plan, SAIL is coming up with a state-of-art cold rolling mill at Bokaro Steel Plant. The decision to build the Cold Rolling Mill Complex (CRMC), was taken to add value to the hot mill product. The surplus capacity of the hot strip mill at BSL presented an opportunity to add further value to the product by cold rolling and coating of the strip, thus requiring the installation of the pickle line, tandem mill, annealing and galvanising plant. This would, on the one hand, improve the profitability of the company substantially and, on the other, enable BSL to gear itself up to face the new emerging industrial scenario in the country, particularly the automobile and white goods sectors. The 1.2 MT capacity unit is under commissioning and shall be ready for commercial production by the end of 2015.

MECON has been appointed consultant for this project. This paper presents the approach, product mix, technology & equipment / facilities selected to roll 1.3 MT hot rolled coil from the existing Hot Strip Mill.

Keywords: Cold Rolling Mill, Auto Grade Steel, Product Mix, Technology

INTRODUCTION

Automotive sector accounts for roughly 12% of the overall global steel consumption. Steel is the dominant material in automobile manufacturing, accounting for roughly 60% of the weight of an average automobile. India is estimated to become the world's fourth-largest automobile manufacturing country by 2020, growing from the current 3.5 million units to about seven million units. Considering 650-750 kg of steel is required to produce a unit, the total market size is huge. Unfortunately, India has to rely on imports for auto grade steel. India imported 7.9 mt of steel in the fiscal ended March, 2013 of which auto-grade steel was about 3 mt.

As a part of massive modernization and expansion plan, SAIL is coming up with a state-of-art cold rolling mill at Bokaro Steel Plant. The decision to build the Cold Rolling Mill

Complex (CRMC), was taken to add value to the hot mill product. The surplus capacity of the hot strip mill at BSL presented an opportunity to add further value to the product by cold rolling and coating of the strip, thus requiring the installation of the pickle line, tandem mill, annealing and galvanising plant. This would, on the one hand, improve the profitability of the company substantially and, on the other, enable BSL to gear itself up to face the new emerging industrial scenario in the country, particularly the automobile and white goods sectors. The 1.2 MT capacity unit is under commissioning and shall be ready for commercial production by the second half of 2015.

MECON has been appointed consultant for this project. About 1.3 MT of Hot rolled coil from the existing Hot Strip mill shall be used as input material for the Pickling line coupled with 5 stand Tandem Cold mill (PL-TCM). Part of the product from the PL-TCM shall be further processed through the Electrolytic cleaning line and Bell Annealing Furnace route or directly to Bell Annealing Furnace. After bell annealing the material shall be skin passed in the single stand skin pass mill. The rest shall be processed in the Hot Dip Galvanizing Line. One (1) Tension leveling & Inspection line shall be installed in the CR complex. Also, two (2) Coil packaging lines shall be provided for the finished product.

Demand Pattern of CR market:

The entire CR market can be broadly classified into two groups, viz, commercial and special groups. Commercial quality is demanded by tube makers, furniture makers, rolling shutters manufacturers and the construction industry, e.g., for roofing. The special groups consist of automobile and white goods manufacturers who demand a very high quality product. The comparison between the two groups in terms of quality and quantity are enumerated in the Table 1.

Table 1: Comparison of commercial quality and special quality

Factor	Commercial quality	Special quality
End use	Tube, Furniture, Rolling shutters etc	Automobile, White goods
Product grade	Ordinary carbon steel	DD,EDD quality
Surface finish	Moderate	Highest quality
Paintability	Moderate	High
Corrosion resistance	Moderate	High
Drawability	Moderate	High
Weldability	High	High
Dimensional accuracy	High	Very high
Chemistry of material	Fairly accurate	Very accurate
Ultimate Tensile strength	High	High or low depending on end use

Factor	Commercial quality	Special quality
Quantity demand	High	Low
Variation of grades	Small	Large
Batch size for production	Large	Small
Cleanliness of factory environment required	Moderate	High
Cleanliness of end product required	Moderate	High
Inspection required	Random	High percentage

Some important market segments for CR product and their typical quality requirement are enumerated in Table 2.

Table 2: Typical requirements of some market segments

Market Segment	Typical Requirements
Automotive	• Extra deep drawing quality • Superior surface finish for exposed parts • High bake hardenability steels for some parts • Galvanized / galvannealed sheets for corrosion resistance
Marine freight containers	• Corrosion resistance steel base • High strength steel • Good surface finish
Bicycles	• High Strength • Good weldability
Packaging	• Medium to high strength • Weldability • Superior surface finish
Roofing	• Corrugated for strength • Galvanized for corrosion resistance • Thin sheets, light yet durable
Home appliances	• Deep drawing / extra deep drawing • Corrosion resistance • Shiny surface appearance • Colour coated sheet

Methodology of Technology Selection:

A lot of thought went into closing appropriate technologies in Bokaro Steel's new CRM complex (CRM-III) keeping customer requirements, processing flexibility and capital cost in view. Several distinct stages were involved in technology selection which includes:

- Literature and industry Survey
- Study of technology issues practiced by current mill operators
- Visits to facilities of mill operators and discussions with their experts
- Discussion with major suppliers
- Discussion with Bokaro steel on operating difficulties in their existing CRM complex (CRM-I & II)
- Data on international benchmarked for production parameters
- Degree of automation
- Evaluation of competing technologies such as Hot dip Galvanizing line vis a vis Electro Galvanizing , Bell annealing batch operation vis a vis Continuous annealing line, Acid regeneration of roasting type vis a vis fluidized bed type, coupled and uncoupled pickling and tandem cold mills
- Identification of suppliers of international repute and evaluation of their capabilities and actual performance.

Selection of Technology for the CRM complex:

The selection of technological features and reasons for the selection are enumerated below in Table 3.

Table 3: Critical Technology Choices

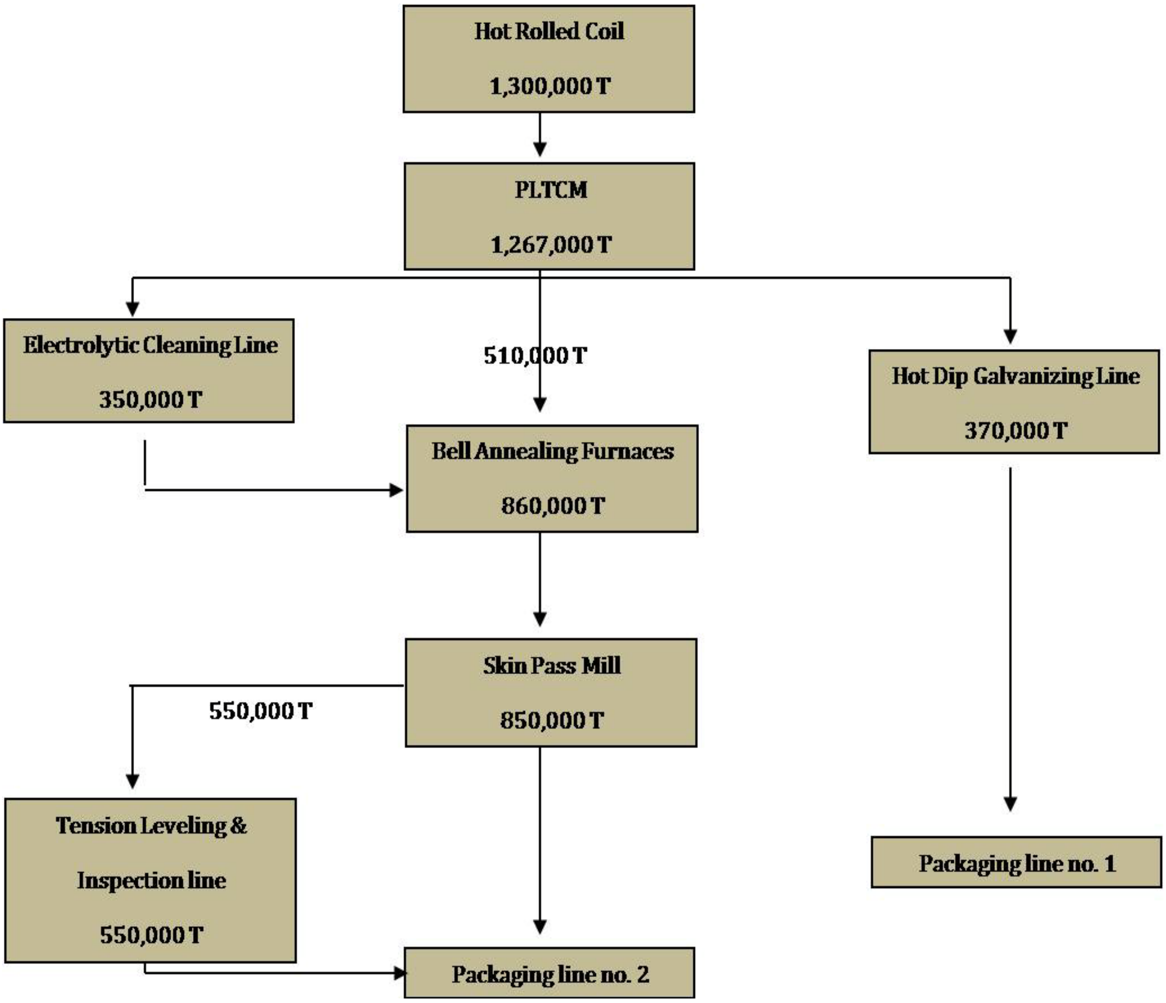
Production Centre	Technology chosen	Reason for the choice
• Coupled Pickling line and 5 stand Tandem cold rolling mill	a) Coupling of PL and TCM	• Higher Productivity as compared to coil by coil operation • Better yield due to continuous operation • Better uniformity of surface conditions due to pickling process being done at same speed • Lesser damage to pinch rolls and steering rolls because of absence of threading and tailing operation • Better uniformity of product quality across length and width during rolling because of stable operating condition • Lower specific consumption of energy • Lower consumption of rolls • Lower consumption of rolling oil & other consumables • No intermediate storage of coil at TCM, thereby saving space and crane operation

	b) Shallow bath pickling	• Lower construction cost • Lower acid consumption • Flexibility of operation because of faster response to changes in requirements which occurs frequently for production of automobile and white goods grade
	d) Turbulent Pickling by Recirculation system	• Effective Pickling and hence good surface quality • Less acid consumption • Minimum over-Pickling or under-pickling
	e) Laser welding	• Better quality of welding • No limitation on grade of steel to be welded
	f) 6 Hi Rolling mill	• Better strip flatness and profile control • Suitable for high quality product for varying widths • Both work rolls and intermediate rolls positive and negative bending facility for better shape control • Facility for using cylindrical rolls at present as well as contoured rolls in future
	g) Roll coolant	• Different concentration of roll coolant for different stands thereby effecting very clean strip
	h) Strip flatness control	• Si-flat (Patented by Siemens) shape measurement – non contact type – to work in conjunction with Automatic flatness control system
• Electrolytic cleaning line	a) High speed cleaning (Process speed – 240 m/min)	• Productivity higher
	b) High cleanliness (Oil content, iron content)	• To attain highest quality for end product
	c) V Type strip movement	• Ensuring higher retention time in chemical cleaning & Electrolytic cleaning section
	d) Continuous cleaning operation	• Productivity higher • Effective cleaning because of same process speed
• Bell Annealing Furnaces	a) Batch annealing	• Lower capital cost • Lower operating cost • Suitable for smaller lot sizes for various grades • IF/BH quality can be made conveniently which is demanded by automobile industry

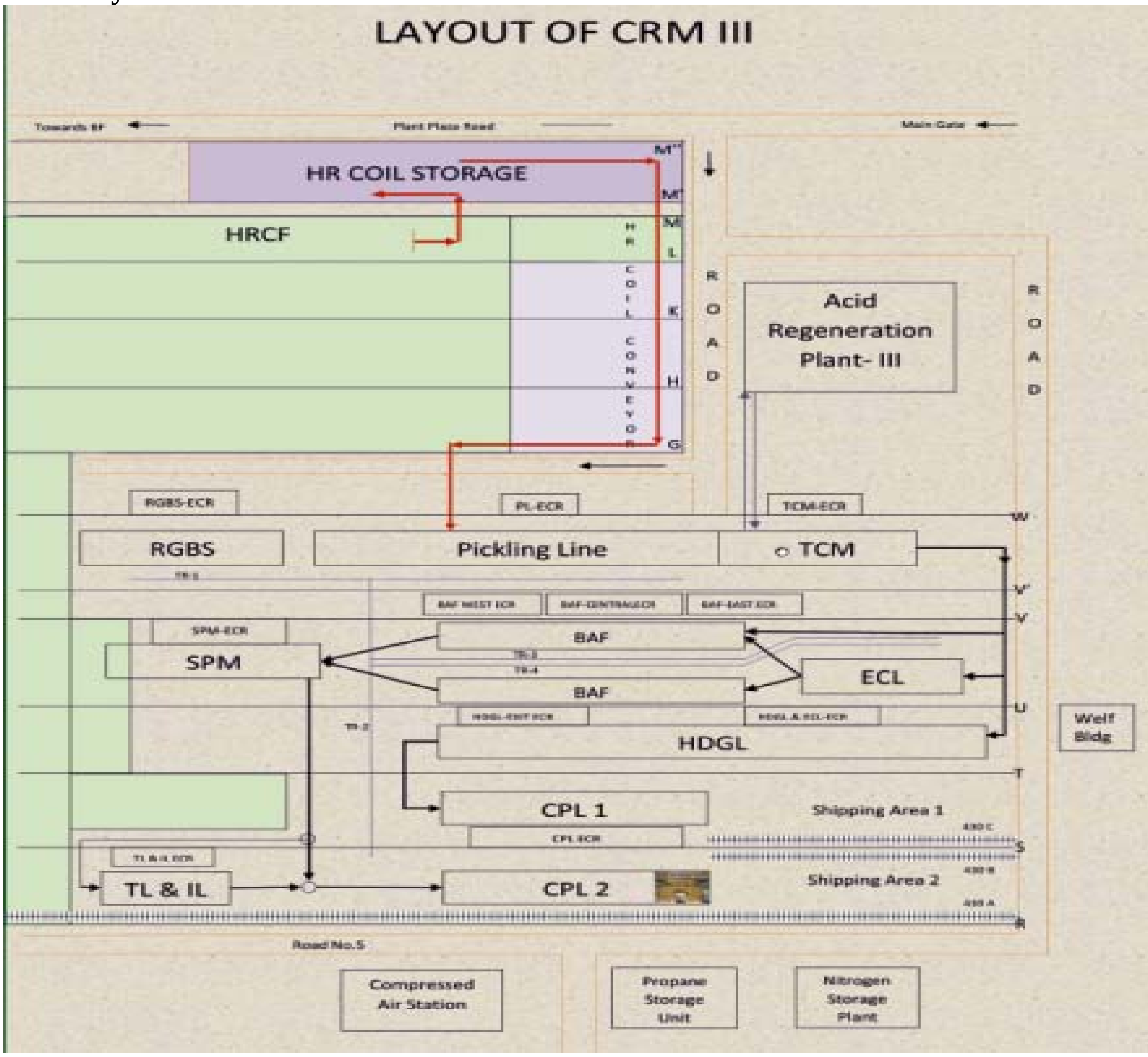
• Hot Dip Galvanizing line	a) Continuous process	• Stable operating conditions • Higher productivity • Low operating cost
	b) High line speed	• Productivity
	c) Combination of Direct fired furnace and Radiant tube heating/soaking	• Lower line length • Effective in cleaning residual oil on strip • Radiant tube heating/soaking ensures a clean strip • Radiant tube heating/soaking also ensures various grades of steel production by accurately controlling heating rate
	d) Furnace fuel	• DFF fired by Propane gas • RTH/RTS fired by Mixed gas • All the burners designed for using Coal bed methane as a fuel in future
	e) Dak-E type air knife (Siemens VAI patented)	• For ensuring zinc coating thickness control both across the length and across the width
	f) Laser welder at entry	• For highest quality of weld • No limitation on steel grade • Allows coil to be cut at any position as per ordering weight allowing smooth weld spot inside the coil
	g) Galvanneal facility	• Both GI and GA strip can be produced • GA furnace can be taken out of line during GI operation
	h) Direct Quenching (DQ) facility	• Allows cooling at controlled rate for various grades • Ensures suitable temperature for skin passing
	i) Differential coating facility	• For meeting customer needs
	j) Over and under unwinding and rewinding facility	• Flexibility of strip bottom part to become outer surface in case bottom surface is better
	k) Provision of addition of one overaging section in future	• For producing TRIP steel in future
	l) Rubber sleeve on Tension reel mandrel	• To avoid scratch mark on the inner wrap • To avoid scratch mark on mandrel surface
• Skin Pass Mill & Tension Leveling	a) Two sizes of work rolls	• Higher size work rolls (600 mm dia) for roughness impartment on IF steel • For all other grades, 450 mm dia work rolls shall be used

	b) Shape control & Elongation control	• Provided for high quality of finished product
	c) Wet Skin passing facility	• Both dry and wet skin passing is possible • Wet skin passing ensures clean strip with adequate air wiping system
	d) Electrostatic oiler at delivery	• Ensures uniform layer of anti rust oil for better preservation of coil

Material Matrix of CRM complex



Plant Layout of CRM-3



Bird's eye view of CRM-3

Production Parameters:

Incoming Material	:	Hot rolled coils for HSM
Yield strength	:	200 to 550 MPa
Tensile strength	:	680 MPa max
Grade	:	CQ/DQ/DDQ/EDDQ/IF/HSS/DP/TRIP/BH

Coil data:

Entry Coils

Thickness	:	1,6 to 5.0 mm
Width	:	850 to 1600 mm
Coil ID	:	810-850 mm
Coil OD	:	2300 mm max
Coil Weight	:	32 tons
Specific coil weight	:	20 kg/mm max

Exit Coils

Thickness	:	0.25 to 2.0 mm
Width	:	800 to 1560 mm
Coil ID	:	508 mm
Coil OD	:	1000 to 2000 mm max
Coil Weight	:	31 tons
Specific coil weight	:	20 kg/mm max

Product mix:

Product	***Production, tpy***
CQ	406608
DQ	97008
DDQ	97008
HSLA	87376
IF	129000
BH	43000
Galvanized	
DDQ	109000
EDDQ	81000
IF-DDQ	54000
IF-HSS	17000
BH	47500
DP	33500
Galvanealed	
IF-DDQ	12000
IF-HSS	12000
BH	9500
DP	4500

Volume of Work:

CIVIL	
Earthwork	438830 cum
PCC	43562 cum
RCC	201400 cum
STRUCTURAL	25000 T
Equipment Weight	35000 T

The main facilities installed in the new CRM complex (CRM-III) at Bokaro Steel Plant are listed below:

Pickling Line & Tandem Cold Rolling Mill (PLTCM)

- Supplier – Siemens VAI
- Capacity – 1300,000 tpa
- Threading speed – 60 m/min
- Pickling Line process speed – 200 m/min
- Mill speed (max.) – 1200 m/min
- Production Capacity – 1.26 mtpa
- Acid fumes (inside bay) – < 5 ppm in H+
- Strip Flatness – 10-12 I units
- Surface quality residual oil– 250 mg/m^2/side
- Surface quality iron fines–100 mg/m^2/side

Batch Annealing Furnace (BAF)

- Supplier – RADCON
- Capacity – 850,000 tpa
- 100 % hydrogen annealing furnace
- 42 bases with controlled cooling bases
- cold rolled close-annealed {CRCA} coils of IF/BH quality

Skin Pass Mill (SPM)

- Supplier – Danieli
- Capacity – 850,000 tpa
- Mill speed (max.) – 1200 m/min
- Elongation – 0.5% to 3.0%
- Surface density of oiling – 0.5 - 3 gm/m^2
- Strip Flatness – 8 to 10 I units

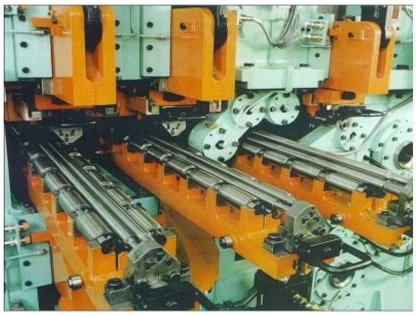
Electrolytic Cleaning line

- Supplier – Siemens VAI
- Capacity – 350,000 tpa
- Speed - 240 m/min
- Residual oil surface – 5mg/m^2/side
- Residual iron fines –10mg/m^2/side
- Yield – 98%

Hot Dip Galvanizing line (HDGL)

- Supplier – Siemens VAI
- Capacity – 370,000 tpa
- Process speed – 30 to 180 mpm
- Entry and Exit Sections – 250 mpm max
- Threading speed – 60 mpm
- Coating Mass
  GI–30 to 300 g/m^2 (each side)
  GA–30 to 100 g/m^2 (each side)
- Differential coating,
  GI & GA–30 to 130 g/m^2 (each side)
- Surface Flatness – 5 I units
  (with tension leveling)

Tension leveling, Recoiling and Inspection Line



- Supplier–Tenova
- Capacity– 550,000 tpa
- Strip speed at Tension Leveler –500 mpm
- Threading speed–30mpm
- Strip flatness–3-4 I units

Continuous Packaging line No.1 & 2 with yard management system

- Supplier–ITW India Limited
- Capacity CPL#1 – 400,000 tpa
- Productivity CPL#1 – 5 coils/hr
- Capacity CPL#2 – 1000,000 tpa
- Productivity CPL#2 –10 coils/hr

Roll Shop

- Supplier–POMINI TENOVA
- Work Rolls for Texturing – 800 nos. / yr
- Grinding Work Rolls – 1320 nos. / yr
- Grinding IMR – 400 nos. / yr
- Grinding BUR – 40 nos. / yr
- Cycle time for grinding
  - Work roll – 45 min
  - Intermediate roll – 55 min
  - Backup roll – 170 min
- Cycle time for texturing – 45 min

Danieli PLTCM in Yieu Phui Technometals, China for Production of High End CR Strips for Automotive Application

Michele Turchetto[1], Sanat Bhaumik[2] & Saugata Das[2]
[1]Danieli Wean United, Italy
[2]Danieli Wean United, India
Email: sk.bhaumik@india.danieli.com

In January 2013 Danieli Metallurgical Equipment (DME), China signed a contract with Yieh Phui Technometals for the design, engineering, supply and installation of a new Pickling Line and Tandem Cold Mill (PLTCM) that was installed in the existing facility of Changshu (Jiangshu Province, China), which is a fully-owned subsidiary of the Taiwanese group E-United. On February 15th, 2015, just 4 days before the Chinese Spring Festival, this continuous pickling line coupled with a tandem cold mill (PLTCM) produced the first cold rolled coil.

This new PLTCM is one step of a strategic capacity expansion project of approximately 1.1 million tons per year of the Yieu Phui Changshu operation facilities. The expansion was needed to produce high quality sheets including inner and outer panels for the Chinese automotive market. Danieli was awarded the entire EPC supply of the mechanical, electrical and control systems, and most of the manufacturing was also done in Danieli China workshops located in close proximity to the installation site.

This state-of-the-art line is designed to produce high end cold rolled strips and the product mix includes all grades of Forming Steel, Structural, High Strength and Advanced High Strength Steel (AHSS) for automotive applications. The line will operate in fully automatic and hands free mode. It is equipped with double pass entry section with laser welder, six strand horizontal looper, scale breaker, Danieli patented Turboflow pickling section, Carousel-type Operator-friendly Side Trimmer, Five Stand 6-High Tandem Mill and High Speed Exit Section with Carousel Coiler.

Thanks to the fruitful cooperation between the teams of Yieh Phui and Danieli, the first coil was produced only two months after the completion of the erection works. The success of this project was a significant milestone for Danieli in China, allowing it to extend its business of strip processing lines to the Chinese and South East Asian market. With almost 57-58 mtpy production capacity of HRC production (including HSMs under installation) and only about one third of these coils are cold rolled / galvanized for CRCA and coated products, such PLTCM will also find new opportunities in Indian steel sector.

Keywords: PLTCM, Advanced High Strength Steel, Automotive Applications

INTRODUCTION

During the first quarter of 2015 Yieu Phui Technometals in P. R. China commissioned a state-of-the-art new Continuous Pickling Line coupled with a 6-High 5-Stand Tandem Mill

(PLTCM) for production of High Strength Steel grades mainly for Automotive Market Applications.

In January 2013 Danieli Metallurgical Equipment (DME), China signed a contract with Yieh Phui Technometals for the design, engineering, supply and installation of a new Pickling Line and Tandem Cold Mill (PLTCM) that was installed in the existing facility of Changshu (Jiangshu Province, China), which is a fully-owned subsidiary of the Taiwanese group E-United.

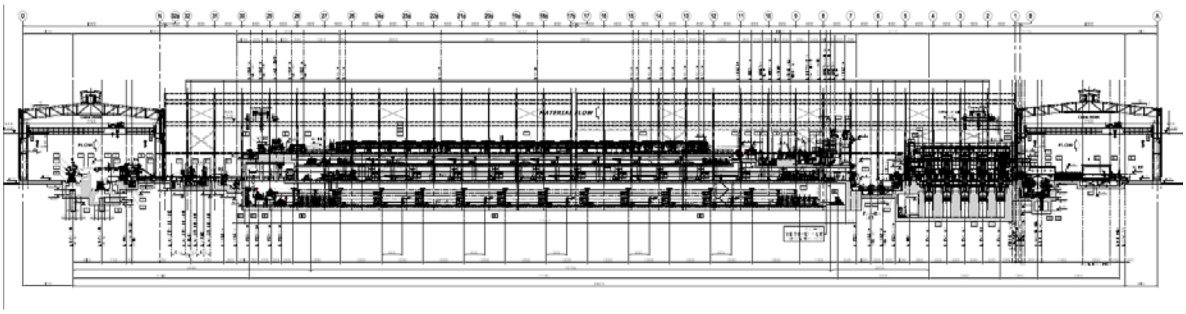


Fig 1: Longitudinal Section View of the PLTCM

This new PLTCM is one step of a strategic capacity expansion project of approximately 1.1 million tons per year of the Yieu Phui Changshu operation facilities. The expansion was needed to produce high-quality sheets including inner and outer panels for the Chinese automotive market. Danieli was awarded the entire EPC supply of the mechanical, electrical and control systems, and most of the manufacturing was also done in Danieli China workshops located in close proximity to the installation site.

LINE & MATERIAL DATA

Material	Grade	Forming steel, Structural, High Strength and Advanced High Strength Steel for automotive applications			
	Thickness	Entry	1.8	6.0	mm
		Exit	0.20	2.5	mm
	Width	800	1650		mm
	Coil Weight	Max 35.0			tons
Speed	Entry Speed	Max	600		mpm
	Pickling Sped	Max	220		mpm
	Rolling Speed	Max	1,200		mpm
Welder type	Laser type				
Pickling process	Danieli Turboflo®				
Mill Type	Stands 1 to 5: - 6-High Mill with IR shifting - Max rolling force 25 MN/stand				
Coiling Type	Carousel Reel with in-line inspection				

ENTRY AND PICKLING SECTION

In the entry section the hot coils are transferred to the hot coil storage saddles by overhead crane; afterwards, via a transfer car the coils are moved to the cradle rolls, the coil is manually de-banded. With the help of the width and OD measuring device located just before the payoff reel, the coil car transfers the coil onto the mandrel automatically according to the signal from the OD and Width measurement.

Fig 2 Entry Section of the PLTCM

While the previous coil is unwounded by the first payoff reel and processed, the next coil is charged on the second payoff reel. The strip is threaded through the flattener to the shear and the head end is prepared. The strip is threaded up to the deflector pinch roll, where the two pass-lines meet together. When the previous coil is finished, the off-gauge strip is divided from the coil at the shear, and the welding cycle to join the coils can start. During the welding cycle the tail end of the just finished coil can be scraped at the shear.

A laser welder joints the tail and the head to guarantee a continuous process. The welder is able to produce welds that can be rolled in the tandem mill. The strip accumulators have been proposed with a low profile design to minimize building height in order to reduce overall costs. This is a proven design first developed by Danieli Wean United and applied over the past 10 years. The entry looper is used to feed the process section during welding phase. The intermediate looper, together with the exit looper, are used to accumulate strip coming from the process section during the side trimmer width adjusting and mill roll changing operation.

Fig 3 Laser Welder

The heavy duty scale breaker is a proven Danieli Wean United (DWU) design in operation at many applications world-wide such as LTV, Dofasco, Sollac, An Feng, Corus, Stahlwerke Bremen, Arvedi, etc. It is proposed with two leveling cassettes and one anti-cross bow cassette. Under normal conditions, one leveling cassette will be operating and the second will function as an installed spare. For extreme conditions of high yield/light gauge materials, both cassettes will be operating.

Fig 4 View of a DWU Scale Breaker

Channel-concept Turboflo® Continuous Pickling Section

The pickling section consists of three tanks patented Turboflo® channel type design. The tank design is a so called "turbulence", where the pickling efficiency is a consequence of the breakage of the laminar flow formed both below and above the interface of the strip and the pickling medium. The turbulence generates high kinetic energy of the acid on the phase boundaries.

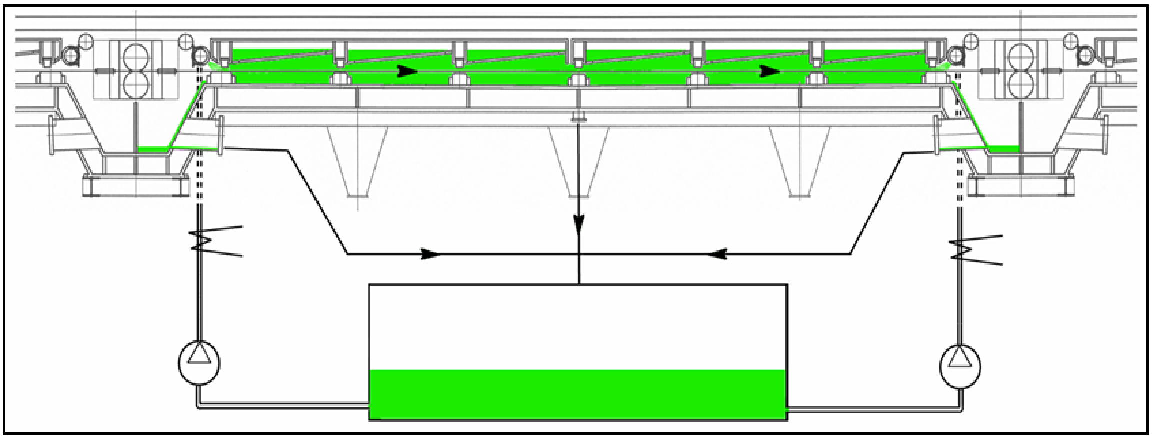


Fig 5 Turboflo® tank with shaped bottom and cover

The turbulence is achieved by an adequate cell concept which consists of (1) the spray location at entry, exit and sides of each tank, and (2) the changes in the section of the pickling channel (realised in practice by shaping both the bottom and the cover of the pickling tank). Each pickling tank consists of multiple cells of approximately 2m length. The tank design has proven to be very effective and reliable in avoiding splashing of acid solution at high speed.

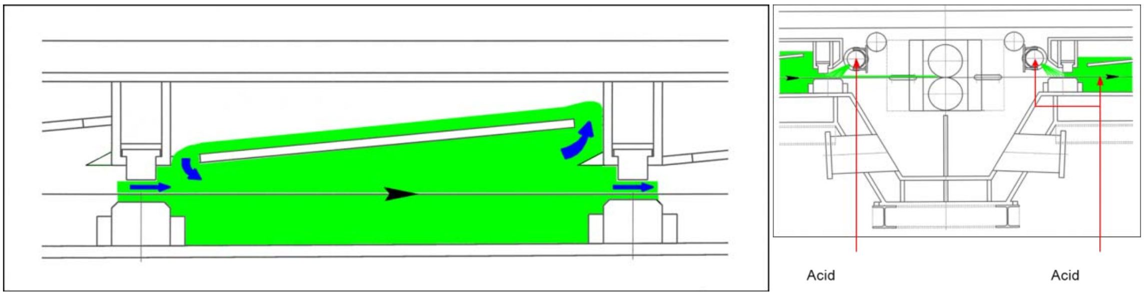


Fig 6 Turboflo® Cell and Spray locations

Fig 7 High-tech continuous Turboflow® Pickling Section

Acid is heated by steam in a carbon fibre heat exchanger located in the main pipe-line between the recirculation tank and the in-line tank. This system allows quick control of the acid temperature, and also allows achieving a high heating power to be transmitted to the acid also at low strip speed, where the highest tonnage per hour of the line is realised. High strip speed produces high turbulence and thus a higher mass-transfer rate. This effect, achieved by the cell design, in combination of the other design features of the pickling tanks (i.e., recirculation system) results in a significant decrease of steam consumption for the heating of the acid by at least of 10%.

Carousel-type Operator-friendly Side Trimmer

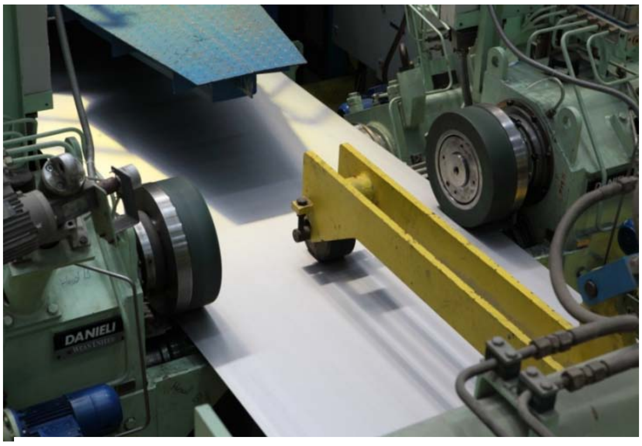


Fig.8 Carousel type Side Trimmer

The side trimmer and scrap chopper unit trims and chops both the edges of the strip, and the whole system is mounted on rotating platforms. Safety is the key issue of the innovations applied to this machine. Two rotating bases are provided to change the side trimmer and scrap chopper heads quickly. Each base is rotated by 180° by a rotary actuator and the travel wheels are driven by a hydraulic motor. The position of the knives is automatically regulated and follows the strip width by means of hydraulic cylinders and position transducers. The two platforms are designed to guarantee the operator the ease and safety changing of the side trimmer and the scrap chopper knives.

The bases when rotated are locked into place by hydraulically operated wedges. The bases are secured in place with hydraulic clamps, against rotation and displacement. Two side trimming heads with upper and lower knives are provided for each rotating base. The knives are mounted on idle arbors, which are located with their bearings in eccentric bushings. The clearance between the upper and lower knives is automatically adjusted by an electro-mechanical screw system. The side trimmer housing is designed to prevent any dangerous operations from being carried out on the machine – this function is controlled by the operator from the control pulpit.

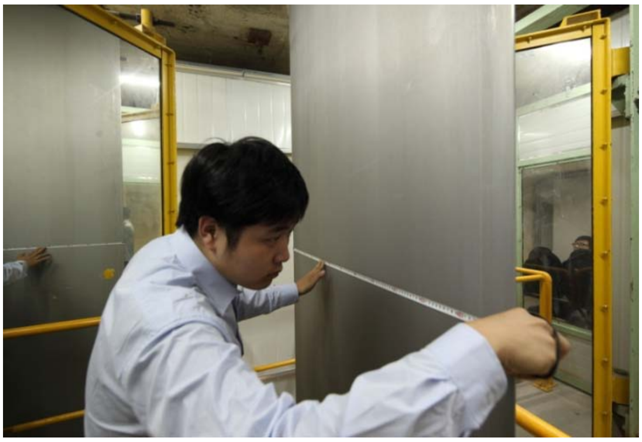


Fig.9 Strip width random check after trimming

Five Stand 6-High Tandem Mill

The strip from the side trimmer passes through a 900 turning device and enters the 5 stand 6hi Tandem Mill. The tandem mill is designed to produce material in high-strength and dual-phase and TRIP grades, where flatness performance requires mechanical equipment with new, accurate and sophisticated models.

Superior flatness correction has been achieved thanks to the installation on each stand of:

Fig.10: A view of the Tandem Mill section

- Positive and negative work and intermediate roll bending;
- Intermediate roll shifting with the possibility of using tapered or shaped rolls.

In addition to roll bending, final strip shape is controlled by an in–line shapemeter providing feedback on bending, tilting and selective cooling headers on stand #5.

In addition, it is also possible to shift the work rolls to control strip edge drop.

In order to obtain a precise control of strip thickness, an ultra-low hysteresis HAGC with a newly designed position control and two servo-valves is installed.

A new system has been developed by Danieli to achieve controlled roll bite lubrication. It associates direct lubrication with a traditional re-circulating system. Consequently, the lubrication effect can change, if and when required, keeping the friction coefficient of the roll bite as stable as possible in all mill conditions.

The roll change is also designed to simultaneously or individually change each single work or intermediate roll, which is an additional feature of the Danieli mill design.

High Speed Exit Section

The Danieli heavy-duty flying shear, together with the carousel reel, ensures an endless rolling process, with cutting and threading speed up to 300 m/min. The flying shear has two drums, top and bottom, which are maintained in the parking position by the electric motor brake. During cutting, the drums are accelerated upto the strip speed. Thanks to the Danieli design, all material grades and dimensions can be cut at a maximum speed of 300 m/min, eliminating excessive mill slowdowns that could cause lower material quality in terms of shape, thickness and surface.

Fig.11: Carousel Coiler at the delivery section

The possibility to cut at high speed and thread a new coil, thus avoiding strip defects in the mill, results from the especially designed carousel reel. The head threading position is extremely short and always in the same position, ensuring perfect coiling of the first wraps. The unloading of the finished coil is always performed in the same position, thus simplifying the coil handling system and lowering production costs. In addition, high speed coil tailing and removal from the carousel will take place 25 seconds after the flying shearing, increasing thick gauge productivity

Danieli Automation for the PLTCM

The entire electrical package - HMI, Level 1 and Level 2 - is supplied by Danieli Automation.

The improved HiPAC suite for PLTCM is fitted with a new adaptive control strategy based on a mix of innovative and traditional regulators to achieve tighter thickness and flatness figures.

Fig.12: A view of theControl Pulpit - Danieli Automation

Thanks to a full set of pickling and rolling models, it is possible to optimize acid, steam and electrical consumption while increasing mill productivity.

OUTLOOK

On February 15th, 2015, just 4 days before the Chinese Spring Festival, this continuous pickling line coupled with a tandem cold mill (PLTCM) produced the first cold rolled coil in the plant of Yieh Phui Technomaterial Co. Ltd., P.R. of China. Thanks to the fruitful cooperation between the teams of Yieh Phui and Danieli, the first coil was produced only two months after the completion of the erection works. The success of this project was a significant milestone for Danieli in China, allowing it to extend its business of strip processing lines to the Chinese and South East Asian market. With almost 57-58mtpy production capacity of HRC production (including HSMs under installation) and only about one third of these coils are cold rolled/galvanized for CRCA and Coated products, such PLTCM will also find new opportunities in Indian steel sector.

Automated Roll Shop Project for New CRM of Bokaro Steel Plant

Pankaj Kumar & Vandana Tembulker
MECON Limited, Ranchi, Jharkhand-834002, India
Email: Pankaj@meconlimited.co.in

For producing value added products like Autobody & appliance grade, a new 1.2 MT CRM-III complex has been installed in the premises of Bokaro Steel Plant. The mill would produce un-coated automotive grade/ high strength steel coils and automotive grade hot dip galvanized coils for domestic as well as export market.

This modern auto-grade cold rolling mill complex demands stringent accuracy & closer tolerances for roll grinding & texturing. The roll changes are more frequent to obtain the desired dimensional accuracy & surface finish of curved rolls by roll grinding. Increase in roll change frequency results in higher volume for grinding & texturing.

A roll shop has been provided for catering to the demand of grinding of rolls for new 5-stand PLTCM, off-line SPM and in-line SPM of HDGL. This is a state-of-the art roll shop with high level of automation conforming to prevalent international standards. The roll shop is a completely self-contained unit and all activities related to the roll assembly and bearing will be carried out within the shop.

Sophisticated CNC roll grinders, CNC automatic roll loaders, EDT roll texturing machines along with other auxiliary machines are installed in the Roll Shop. In order to maintain different types of rolls, chocks, bearings, wheels etc a sophisticated & user friendly tool known as Roll Shop Management system is provided in the roll shop. The Roll Shop Management System (RSMS) is a server based software tool to manage these roll shop equipment. RSMS links all roll handling facilities, both for production and for roll preparation to the system network. RSMS also supplies historical data, inventory, tracking and maintenance information thereby supporting the decisions made on daily basis in the roll shop.

This paper discusses the above roll shop project that has been implemented through MECON by providing consultancy services at the new CRM complex of Bokaro Steel Plant.

Keywords: Roll Shop Management, Roll Grinding, Texturing, Surface Finish

INTRODUCTION

Bokaro Steel Plant (BSL), a unit of SAIL is one of the largest producers of diversified cold rolled products in India having one continuous Hot Strip Mill, one 4-stand Tandem Cold Mill, one 5-stand Tandem Cold Mill and related upstream and downstream facilities. The Cold Rolling Mill (CRM) Complex was installed in two stages, viz. 1.7 Mt/yr stage and 4.0 Mt/yr stage. An ambitious expansion programme was undertaken by SAIL for all the

Steel Plants under its fold to increase the production capacity as well as for diversification of value added products under corporate plan 2011-12. In line with this expansion programme, a new state-of-the-art cold rolling mill (CRM) complex for production of 1.2Mt/yr of finished products has been installed in Bokaro Steel Plant (BSL). The CRM complex would produce un-coated automotive grade/ high strength steel coils and automotive grade hot dip galvanized coils for domestic as well as export market. These products would cater to the automobile and appliance industry.

For the above mentioned new CRM complex, different technological units & services facilities have been installed. The major technological units are listed below:

1) 1560 mm coupled HCL Pickling Line with 5 stand 6- Hi Tandem cold rolling mill (PLTCM)
2) 1560 mm skin pass mill (SPM)
3) Bell annealing furnace
4) 1560 mm Hot dip galvanizing line (HDGL)
5) 1560 mm electrolytic cleaning line (ECL)
6) Tension leveling line including inspection facilities
7) Coil Packaging Lines
8) Roll shop facilities
9) HR Coil Conveyor System

About 1.3 MT of Hot rolled coil from the existing Hot Strip mill is to be used as input material for PLTCM. Part of the product from the PLTCM shall be further processed through the Electrolytic cleaning line and Bell Annealing Furnace route or directly to Bell Annealing Furnace. After bell annealing the material shall be skin passed in the single stand SPM.

The rest will be processed in the Hot Dip Galvanising Line. One tension leveling, recoiling and inspection line is installed in the CR complex. Also 2 nos. coil packaging lines have been provided for the finished product. A Hot Coil Conveying system has been provided to transfer HR coils from the existing coil conveyors to the entry conveyor of the PLTCM of the new CRM.

Monthly Production

The following texturing and roll grinding requirement will be met by the Roll Shop. This corresponds to the requirements estimated for one month consumption in the new CRM complex. The total requirement will be met by using 1 Combi grinder, 2 WR/IMR grinder, 1 EDT m/c and 1 automatic roll loader catering to these four machines.

1. Roll Texturing:

Work rolls of PLTCM:	280
Work rolls of off-line SPM:	400
Work rolls of in-line SPM of HDGL:	120

2. Roll Grinding:

Work Rolls/Intermediate Rolls of PLTCM:	1200
Work Rolls of off-line SPM:	400
Work Rolls of in-line HDGL-SPM:	120
Back-up Roll of PLTCM, SPM & HDGL:	40

ROLL SHOP

A modern roll shop has been implemented for catering to the demand of grinding/ texturing of rolls for PLTCM, off-line SPM and in-line SPM of HDGL. Through competitive bidding & tendering process order was placed by BSL on Pomini Tenova.

The roll shop is state-of-the art with adequate level of automation conforming to prevalent international standards. The roll shop is a completely self-contained unit and all activities related to the roll assembly and bearing are carried out within the shop.

The main equipment installed in the Roll Shop is indicated below:

- Two CNC roll grinding machines for work rolls and intermediate rolls
- One combination CNC roll grinding machine for back-up rolls and work/intermediate rolls
- One Electro-discharge texturing (EDT) machine
- One Automatic Roll Loader for loading/ unloading of WR/IMR to the above three grinders and one EDT machine
- Roll Shop Management System (RSMS)
- CNC Shear blade grinder
- Back-up roll chock changing machine
- Work / Intermediate roll chock changing machine
- Chock tilter for back-up, intermediate and work roll chocks
- Cleaning station for back-up, intermediate and work roll assemblies
- Work / intermediate chock and bearing cleaning machine

The different types of rolls indicated above need regrinding at regular intervals to restore their dimensional, geometrical and structural features. Improvement in rolling technology, reduction of down time of a rolling mill and qualitative needs of CRM flat products have forced roll grinding technology to undergo significant change. The CRM complex needed optimised roll shop layout to provide rolls of fine tuned high surface quality with consistency from roll to roll. As this roll shop is to be shared by three mills, it has the flexibility to quickly change set-ups to service different rolling programmes as well as roll profiles.

There was a big constraint of space for this CRM complex. 1.2 MT capacity CRM complex was to be accommodated in the available space of earlier planned 0.6 MT capacity complex. Because of this space constraint, the roll shop had to be located at one end of the PLTCM, which ideally should have been kept just behind the TCM area. This has resulted in a substantially increased travel of the rolls from TCM to Roll Shop area.

Dedicated roll assembly transfer cars have been provided in the PLTCM bay for this purpose.

To meet the above requirements sophisticated CNC roll grinders, CNC automatic roll loaders, EDT roll texturing machines along with other auxiliary machines are installed in the Roll Shop. Also as this roll shop caters to different mills in order to maintain these different types of rolls, chocks, bearings, etc a sophisticated & user friendly tool known as Roll Shop Management system is employed in these roll shops. The automation level of this modern roll shops is very high to ensure quality, predictable output, safety, increased operator productivity, reduction of routine human intervention and optimised management of roll inventory and movement. A single operator sitting in front of several PCs in the central pulpit controls three grinders, EDT machine and automatic roll loader.

CNC ROLL GRINDERS WITH EDDY CURRENT & UT DEVICE

Two CNC heavy duty work roll grinders HD 409-9-9 (800 x 5500 mm) & one CNC Combi Grinder mode HD 408-0-7 (1350 x 6100 mm) have been installed in the Roll Shop.

The specified hardness, wear resistance and toughness of roll material are very high for rolls of the new CRM complex. Therefore, modern CNC Roll grinders have been installed that are capable of grinding these rolls with high productivity without any defect. Moreover auto grade strip's ever tightening specification for flatness, thickness & surface quality demands the dimensional, profile and geometrical accuracy of the reground rolls to be impeccable.

Present day's roll is a highly stressed part of steel and can explode if not handled carefully and constantly monitored for cracks and other forms of damage. The thermal strains of heat treatment leave residual stresses in the roll which can result in catastrophic failure if cracks or internal defects are allowed to develop into cracks. The CRM rolls use forged steel with increased levels of Cr & Ni. These rolls being very hard are susceptible to a type of failure where hard shell breaks away from the core. Experience with cold mills has shown that most spalls occur from surface initiated cracks, but more recently we have seen faster sub-surface propagation of these cracks, making ultrasonic inspection more important as a follow-up to eddy current inspection of cold mill work rolls.

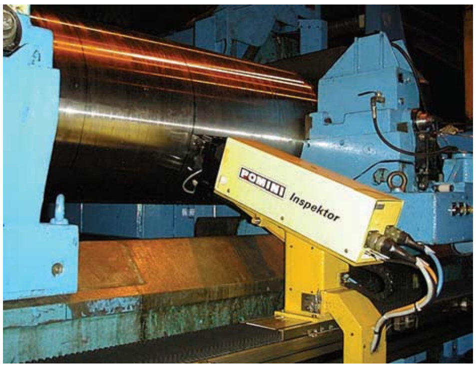


Fig: Eddy Current and UT inspection system to accurately measure surface and sub-surface roll defects

Fig: Independent caliper for 100% roll inspection during grinding

In such cases UT scanning is the most effective method to detect and monitor small crack defects enabling safe & cost effective roll management program. A non-destructive testing (NDT) device is directly integrated with the roll grinders for finding surface and sub-surface defects. Eddy current detects the surface defects and sub- surface defect is detected by UT and thus prevents defective rolls from entering the mill. By classifying the crack levels, NDT based diagnostic system is also used to determine how much stock to remove from the roll, which grind program to use and when to accept the roll - all these decisions were earlier taken by the operator. NDT systems also have vibration analysis module to send alarm to the machine when it reaches a threshold level.

Eddy current inspection analyzes the interaction between applied and induced electromagnetic current. For any set of fixed testing conditions (electrical conductivity, geometry and magnetic permeability), surface discontinuities alter the induced current, signaling some abnormal condition based on the changing ratio of this induced current to the constant applied energy.

The roll grinder of Pomini is equipped with an independent calliper which provides 100% roll inspection and measurement during grinding operation. Eddy current & Ultrasonic detection systems on grinders are fully integrated with automation system. Fully automation systems record and store a detailed 'map' of each roll's defects for future use.

EDT MACHINE

EDT has the ability to texture high alloy high hardness rolls over a wide range of roughness. In EDT the spark plasma locally melts the surface and re-solidifies creating a series of craters, hardness is not a factor in the ability to produce a textured surface. In addition, rolls from a wide range of chemistry can be textured to the same surface roughness and the same surface profile with the same texturing program. Crater formation is controlled by pre-set energy parameters in the program giving a very high degree of repeatability from roll to roll.

Fig: EDT machine

Fig: Textured Rolls

EDT is a fully automated 72-electrode 'Sarclad Rolltex' machine consisting of a servo-controlled moving carriage roll manipulator which supports and rotates the roll as the texture is applied by high precision multi-electrode servos. The machine design is a traversing roll manipulator, with a conventional headstock, tailstock and roll steadies, much like on a traveling table roll grinder, with two static texturing stations, one on either side, as shown in Figure. The design employs multiple electrodes within each texturing station. An array of electrodes is brought to the correct sparking position by each servo-control, so a minimal number of servos are used in this design.

The electrodes are submerged in a bath of dielectric. The bath is pressed against the roll to form a seal even while the roll is turning and traversing. During texturing the roll is traveling across the electrode array and the roll is turning, so the full rolling area of the roll is textured, usually in one pass.

The movement of all components is fully automated and the complete texture process is computer-controlled to ensure a high level of consistency both across each roll and from roll to roll. Automatic positioning of the headstock, steadies and tailstock is carried out by electric motors. Automatic leveling of each roll to a high degree of accuracy is achieved by a Y-gauge system.

The value of Ra used on the roll is dependent on the transfer ratio from the roll to the sheet in the mill. This is invariably affected by the metallurgy of the sheet, the gauge and the rolling force used. Roughness transfer ratios are in the range 30 to 60%.

AUTOMATIC ROLL LOADER

Automatic roll loader has been provided in this modern roll shop. It loads & unloads the grinders & EDT machines in shortest possible time and at the same time reduce the chances of handling damage. It is CNC controlled and is fully integrated with grinders and EDT machine and thus automatically organises the work sequence. As per programme sequence the integrated roll loader system moves the rolls and transfers the corresponding set-up and grinding data sets to & from the grinders & EDT machine.

Fig: Automatic roll loader in operation

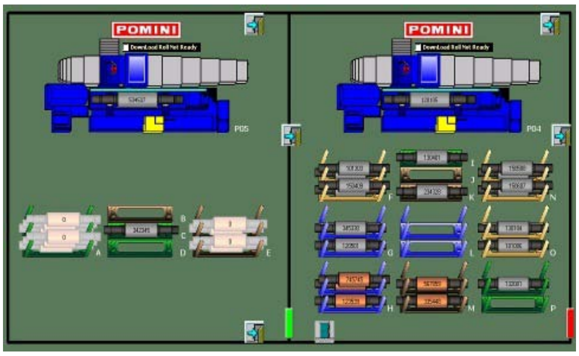


Fig: Automatic area on roll loader screen

The Roll Shop Management System is also interfaced with the Automatic Roll Loading System for the necessary data exchange.

ROLL SHOP MANAGEMENT SYSTEM

The Roll Shop Management System is a server based software tool to manage roll shop equipment such as rolls, machines, chocks, bearings, wheels, etc. RSMS links all roll handling facilities, both for production and for roll preparation to the system network.

RSMS is controlled via the Roll Shop computer system, directly communicating with the mill production system. By combining grinding data with mill production data, RSMS provides performance indicators to derive effective decisions for production, planning and vendor analysis.

RSMS also supplies historical data, inventory, tracking and maintenance information thereby supporting the decisions made on daily basis in any roll shop.

As central information storage the system utilizes an ORACLE database to handle data of all roll shop related components.

The tasks of the RSMS are grouped into two categories:

- database functions
- automation functions.

Database functions take care of the gathering and evaluation of information while automation functions handle the control and monitoring of automatic roll loading and unloading with an auto-loader.

At Bokaro steel plant, RSMS is connected to 3 roll grinders, EDT m/c, roll loader and the 3 mills computers PLTCM, HDGL & SPM.

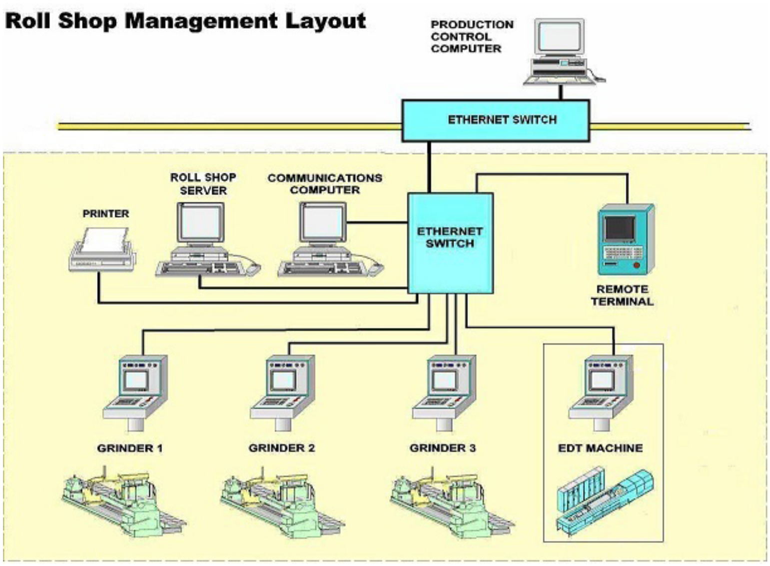


Fig: RSMS configuration for a cold mill

Following typical reports can be generated by RSMS:

- Average roll cost per ton of steel produced for a specific roll material.
- Wheel cost per mm of roll stock removal.
- Total tons of steel produced with each roll.
- Total stock removal for each grinder.

The above information can be used to evaluate different roll suppliers not based on the purchasing cost of the roll, but on the actual cost of the roll when used in the mill, related to its production. A typical screen comparing average tons for each of the three rolls is given below.

Similarly to manage other roll shop equipment, like chocks and bearings, when bearings are assembled into chocks, chocks assembled into rolls, and rolls paired to be sent to the mill, this information is fed into the RSMS. When the above assembly area functions are used, the following reports can be provided by a RSMS:

- Total km of steel produced with each chock.
- Total operating hours of each bearing.
- Maintenance plan for chocks and bearings.
- Tracking information for chocks and bearings

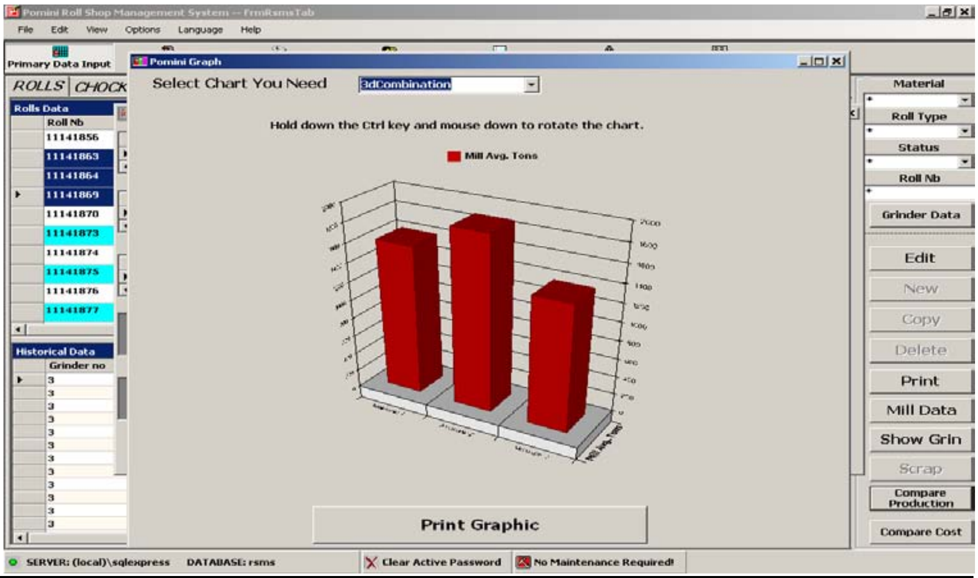


Fig: Graphical comparison of average tons rolled for each roll

There are four main component types to be managed by the RSMS system: rolls, chocks, bearings and grinding wheel. For each component to be handled by the system an account must be created in order to assign upcoming data accordingly. This is done by entering the master data of the components in the database. Typical screens for registering new rolls & chocks are indicated below.

Fig: Screen for registration of new rolls

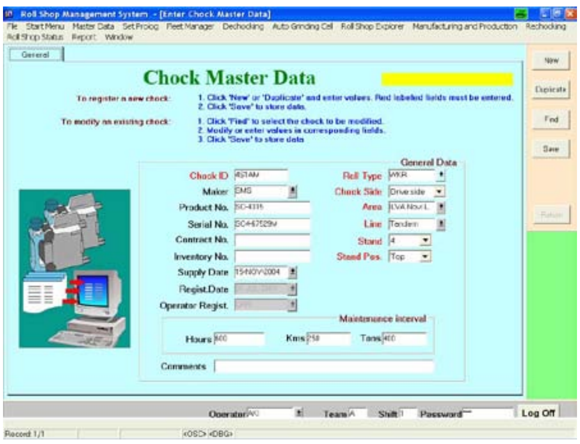


Fig: Screen for registration of new chocks

Each roll has a unique ID to track its movement and record its operational history in the central database. Roll master data holds basic information of a given roll that usually does not change during its life cycle. For example: make, mill, roll type, barrel length, etc

CONCLUSION

A modern Roll Shop has been provided for the new CRM where HR coils from a range of 1.6 to 5.0 mm are rolled to 0.25 to 2.0 mm with a maximum width of 1560 mm. State of the art equipments like CNC roll grinders, EDT machine, automatic roll loaders & RSMS are provided in the Roll Shop. This fully automated roll shop needs no manual intervention in the automated zone apart from occasional scheduled equipment maintenance and replacement of consumables like grinding wheel.

The roll shop is managed by a roll shop management system in which a database manages the whole roll inventory and organizes the trouble free flow of all rolls according to the requirement of the different rolling mills. The long term analysis of RSMS enables optimal usage of roll related components and machines and leads to a cost reduction by purchasing components with the best comparable result in performance and quality.

Analyzing Failures through Customized Metallographic Techniques in Automotive Steel

Shomick Roy, Jitendra Mathur, Manashi Adhikary & Sandip Bhattacharya
R&D and Scientific Services, Tata Steel Limited, Jamshedpur, Jharkhand-831001, India
Email: sandip.bhattacharya@tatasteel.com

Abstract

Automotive steel for high strength and structural components is now the common buzz word. While its unique mechanical property combination against requirement of safety, fuel economy and aesthetics (as desired in automotive) has flourished its high usage, it also leaves behind scope for improvement w.r.t. failures related to forming, welding and surface issues. Herein comes the role of characterization techniques in understanding the root cause of these failures and metallographic investigation still serves to be the basic key.

In this paper, cracking issues emanating during forming in automotive high strength and structural steel components have been investigated. The authors deployed customized etching techniques in revealing the true microstructure and assessing the reason of failure. Non conventional etching revealed banded microstructure and crack flow line was found to follow the banding / segregation line. Meanwhile it overrode conventional etching techniques which however could not reveal true segregation phenomena in these steels. The analysis was supported through optical and scanning electron microscopy and micro-hardness. The approach only indicates that developing alternate techniques of characterization is the need of the day as we advance in automotive steel.

Keywords: High Strength Steel, Metallography, Etching

1. INTRODUCTION

Steels form the major component in an automotive application. With stringent norms of environment and passenger safety, the trend is towards usage of high strength steels. However such steels should satisfy intended performance during component forming and end use. While the processing parameters and design aspects do entail performance guarantee, often these steels possess problems related to forming. Forming defects may comprise of dimensional tolerance or metallurgical issues like cracking or surface defects. In this paper the authors have tried to estimate the root cause of failures mainly cracking related phenomena in two specific high strength and structural component application through customized metallographic etching techniques. The altered technique revealed segregation or banding effects not disclosed under normal metallographic techniques.

2. MATERIAL

2.1 Composition

The starting material was a micro alloyed grade steel with C <0.1%, Mn< 2% (micro-alloying< 0.5%). The second case was a regular C- Mn grade steel with C < 0.2% and Mn<0.8%.

2.2 Visual Observation

The sample worked with were part of formed automotive components, former being part of a long member of automotive and the latter being part of a brake component. The working samples were evident of the defect or crack as shown in Fig 1 and Fig 2.

In the former a irregular crack across the bent portion of the component was observed and in the other, through thickness crack was associated with a centreline mark.

The crack occurred during bending and slitting operation respectively in the above cases.

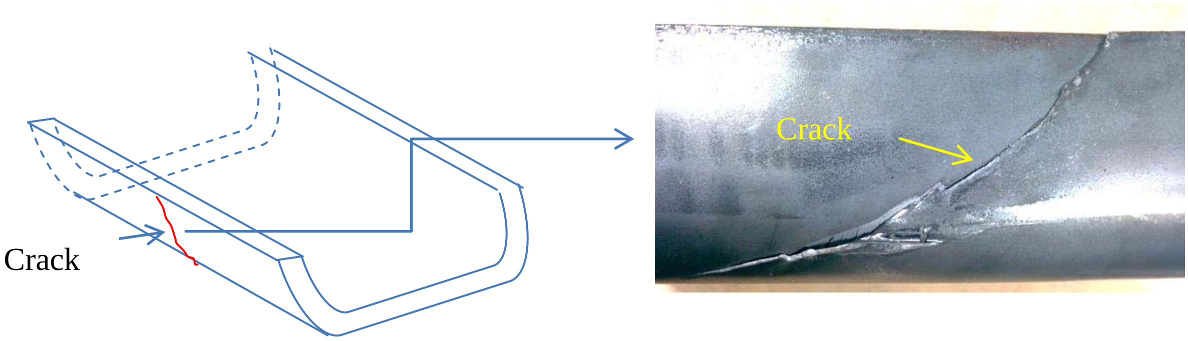


Fig 1 –Sample 1 showing schematic of Long Member Auto Component along with the crack and the side view of the actual sample with the irregular crack along the bent portion. The sample size was ~300 mm along the length axis

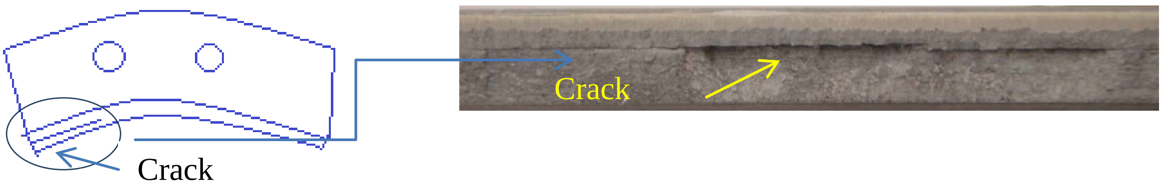


Fig 2 – Sample 2 showing schematic of a brake component and side view of the component with the defect and the crack face. The sample size was ~150mm along the length axis.

3. EXPERIMENTAL DETAILS

3.1 Sample 1 – Micro-alloyed Steel Long Member Component Failure Analysis

3.1.1 Imaging – Stereoscopy

Post visual observation, the sample was prepared for stereo imaging under stereo microscope Leica M165C. The crack was ripped open to reveal the fracture face. Crack initiation was observed at the shear edge of the component and found to propagate inside the material. Observation of shear edge revealed presence of multiple marks (yellow arrow) on the shear edge/ surface. Small cracks were also found to be associated with these marks (Fig 2a, 2b, 2c, 2d.)

3.1.2 Imaging –Fractography

Fractography was conducted under Scanning Electron Microscope FEG-SEM Zeiss SUPRA25 (Fig 2e, 2f and 2g). The fracture study indicated brittle cleavage fracture, transgranular nature with grain boundary initiation. Fracture initiation location (location A) was associated with chevron marks (location B) indicating the fracture propagation direction.

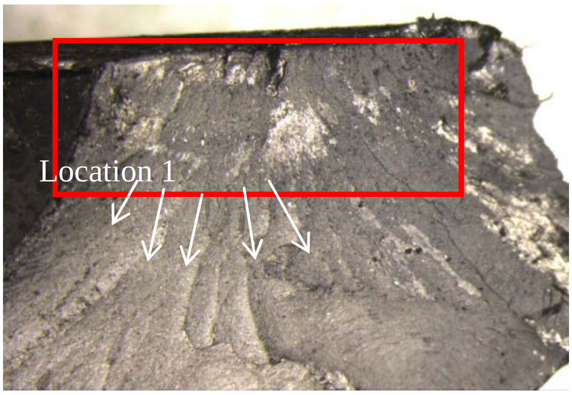


Fig 2a - Crack initiation location

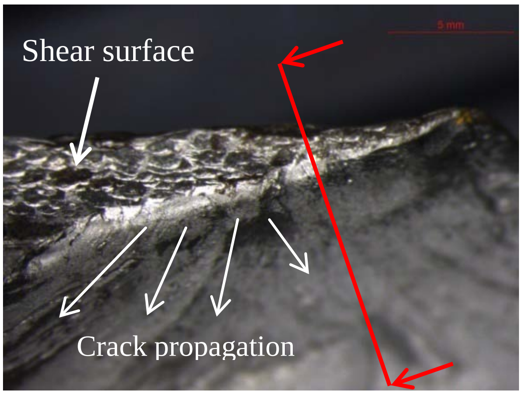


Fig 2b - Shear edge at crack initiation location

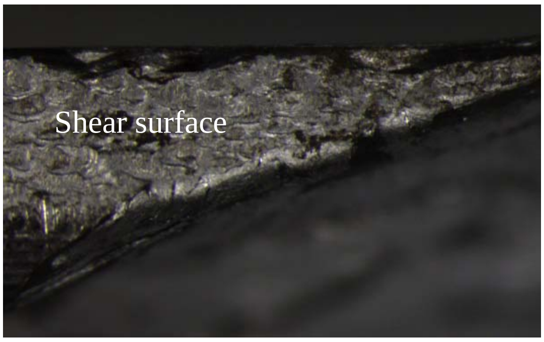


Fig 2c - Shear surface at crack location

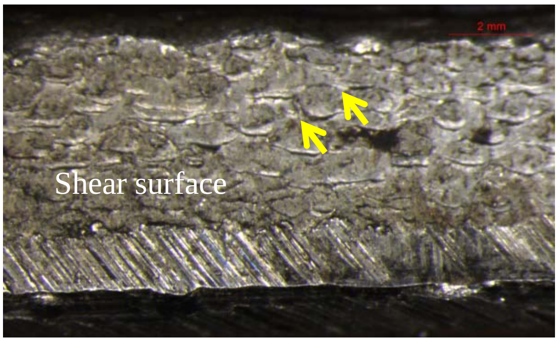


Fig 2d - Shear surface at other locations

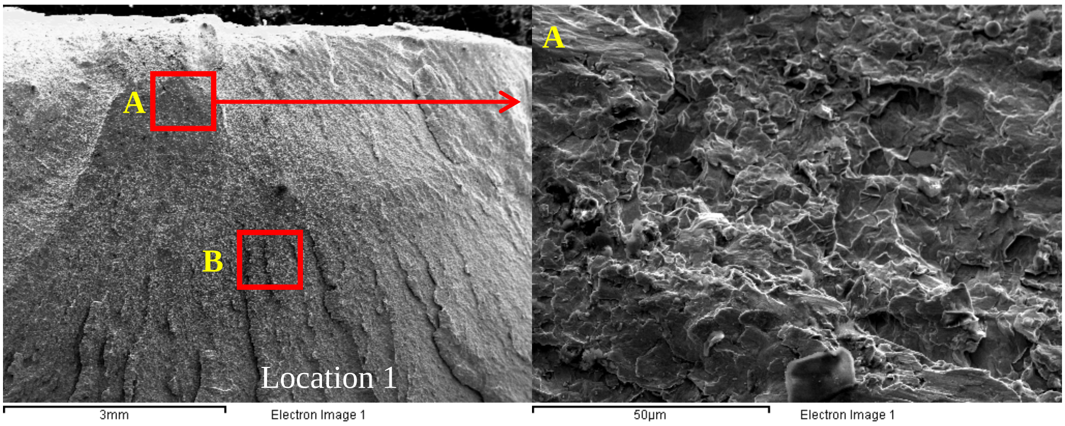


Fig 2e - Fracture initiation location at two different magnifications under scanning electron microscope

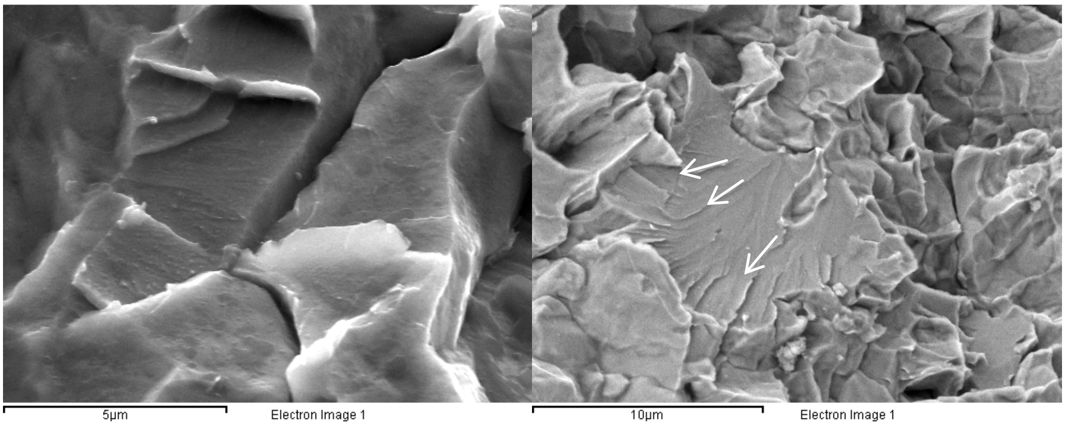


Fig 2f - Fracture facet at initiation location with observation of transgranular fracture showing grain boundary initiation

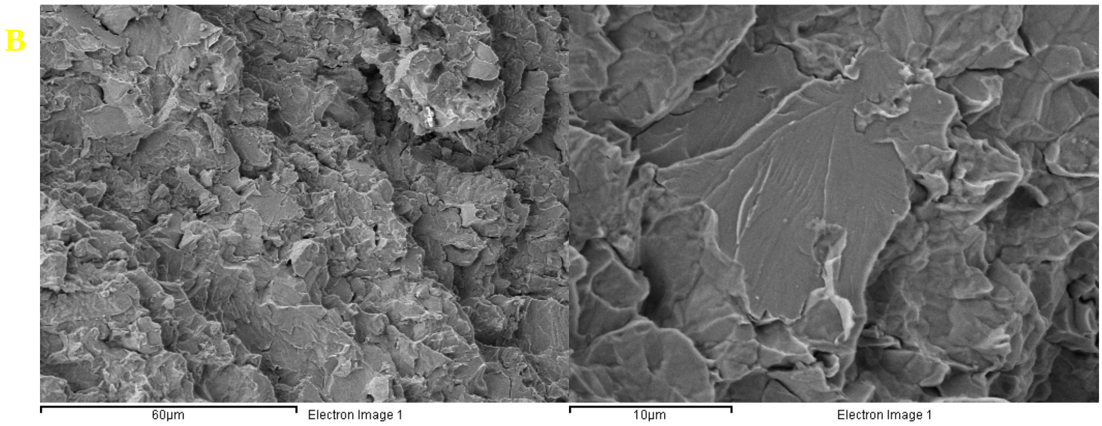


Fig 2g - Fracture surface at propagation zone showing transgranular nature

3.1.3 Imaging – Optical Microscopy and Scanning Electron Microscopy

While fratography could characterize the nature of the fracture, the root cause was yet to be established. As a next step, normal sample preparation techniques for optical microscopy was carried out. Transverse specimen across the crack was prepared to check for subsurface abnormalities or segregation. An optical microscope Leica M205A was used to observe the microstructure.

Normal nital etch 2% however could not reveal any characteristic symptom to the failure. However the crack surface was associated with multiple micro cracks (Fig 3).

With a customized etching technique based on picral at high temperature, the same location revealed banded appearance at the crack location. Distinct difference in grain size was observed in these alternate bands under this new etchant. The crack was found to be parallel to one such segregation band (Fig 4).

Detailed characterization of these bands across the shear edge also revealed variation in grain sizes (Fig 5).

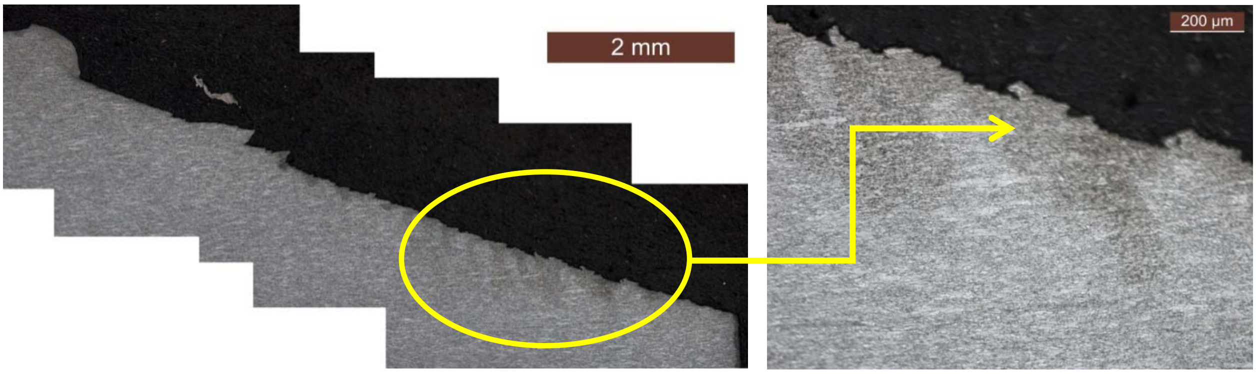


Fig 3 – Optical microscopy on the transverse section of the crack did not reveal any subsurface abnormality under nital etch 2% except multiple micro cracks on the crack face

3.1.4 Microhardness

Micro-hardness comparison in a EMCO Durascan 20 across the bands revealed the following hardness variation:

White bands: 307 HV (50 gm), Dark bands: 276 HV (50 gm)

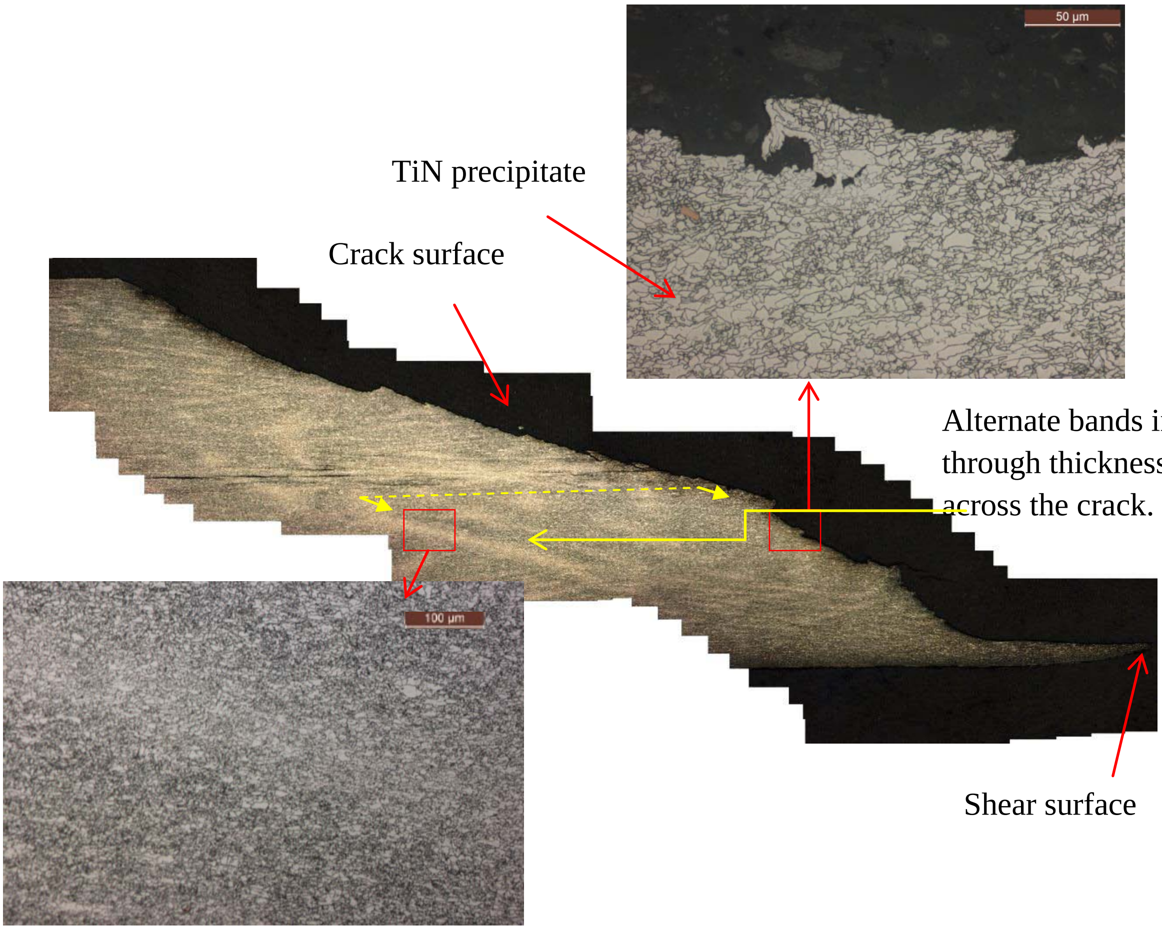


Fig 4 –Microstructure observation etched with customized process and composition revealing banded structure with alternate fine and coarse grains. The segregation lines or bands are found to follow some pattern and the crack face was found to be parallel to one such band.

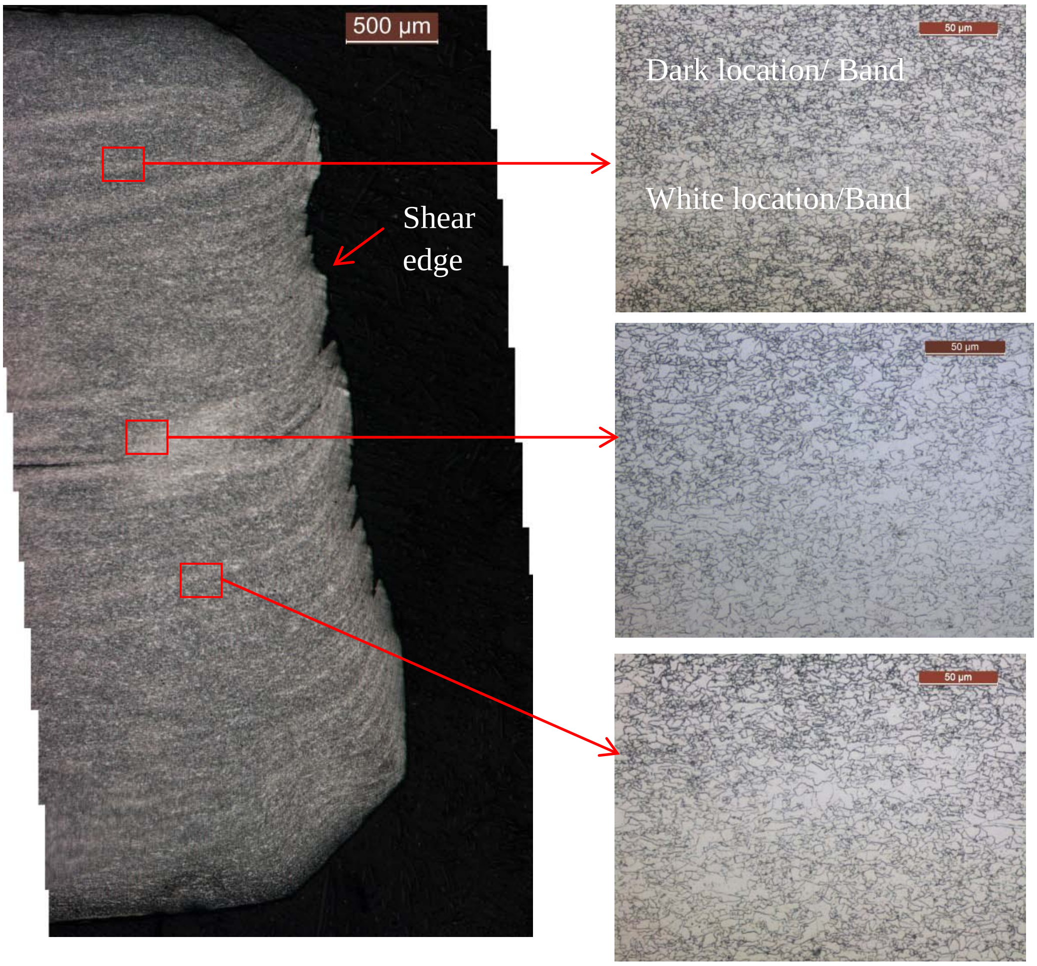


Fig 5 – Optical microscopy under customized etching technique revealing grain size variation across the shear edge.

SEM analysis of these bands further revealed variation in precipitate size and distribution (Fig 6)

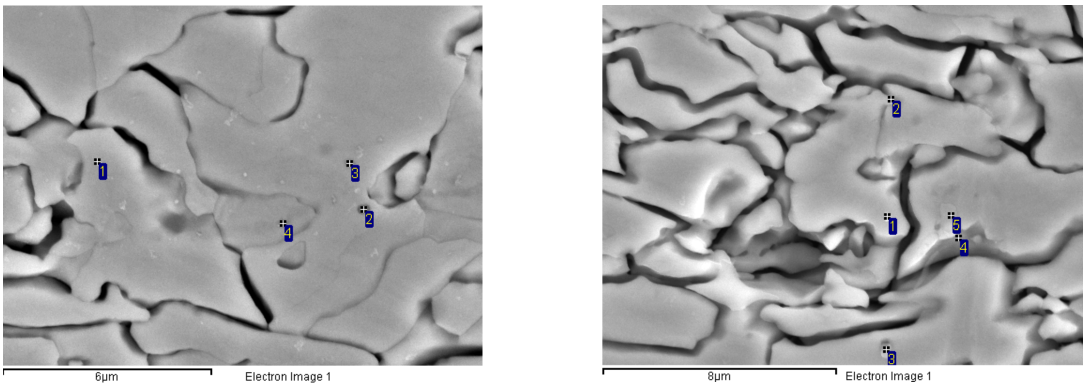


Fig 6 showing precipitate in grain body in bright (left) and dark locations (right). The distribution varied between the two, being lower in the dark locations. The precipitates were checked for composition revealing micro-alloys in the grade along with Mn.

Similar etching technique was applied in the second sample.

3.2 Sample 2– Plain C Mn Brake Component Failure Analysis

3.2.1 Imaging - Optical Microscopy

Transverse microspecimen across the crack location revealed very few MnS stringers (thickness < 2 micron) along quarter line and center-line of the material but no bulk MnS inclusion cluster was observed near or around the crack / separation line. Other than few MnS no other inclusions were observed (Fig 7)

Thereafter this was characterized under conventional etching for steels with 3% nital solution. A boundary less white structure was observed along the crack line. It appeared like ferritic bands.However this could not reveal the reason of failure.(Fig 8)

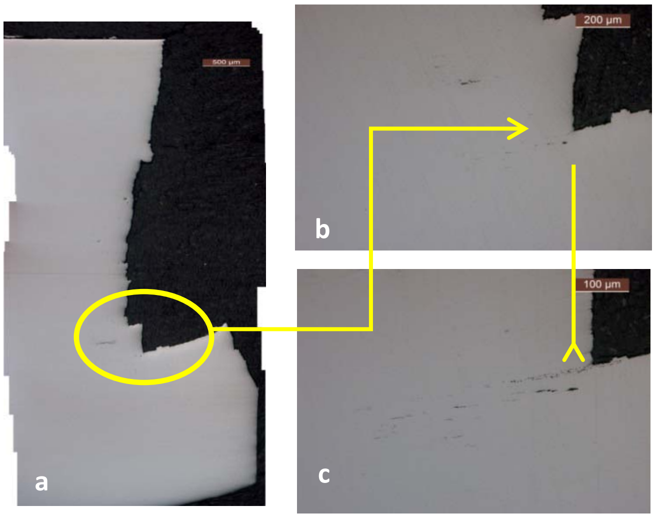


Fig 7 – Transverse micro-specimen showing crack associated with few MnS stringers.

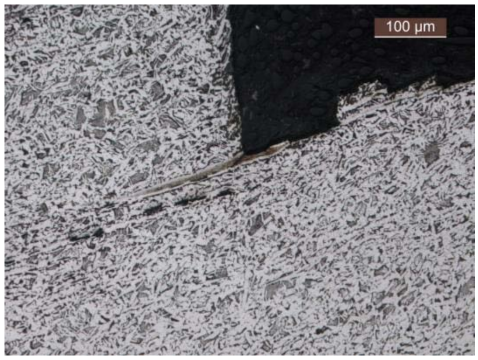


Fig 8 - No segregation line was observed under normal 3% nital etching.

To reveal additional features in crack location samples were etched combined picral and sodium thiosulphate under high temperature (<100 deg C) and this revealed a unique segregation line. The ferritic band like whitish phase under nital etch, revealed as a brownish phase (Fig 9).

Based on color etching the phase appeared to be ferrite however micro-hardness showed significant difference (300 HV) with respect to matrix ferrite (200 HV). Further SEM analysis was carried out to confirm this phase revealed under customized etching. EDS revealed presence of phosphorus along with Mn and Fe in this segregation line.

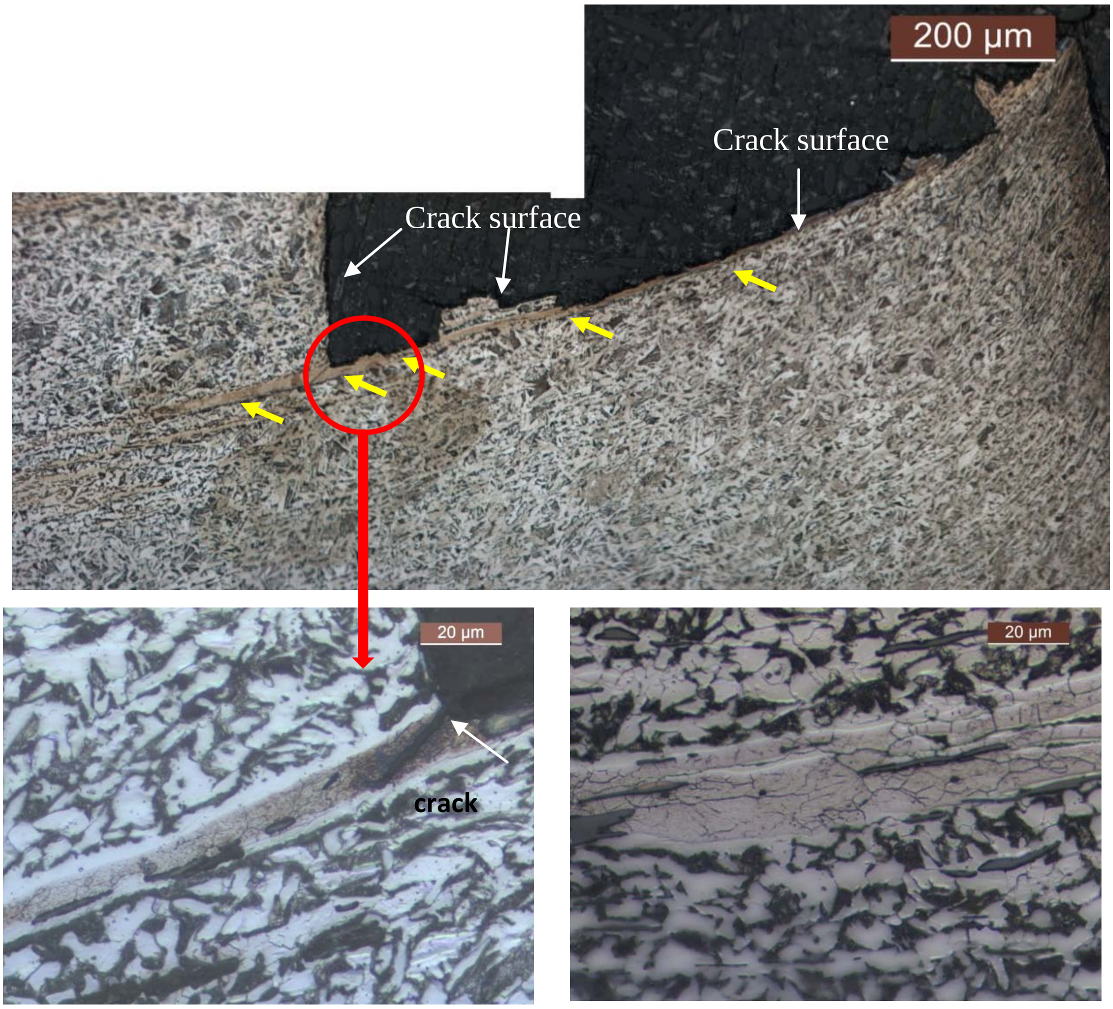


Fig 9 – Color etching revealed a unique segregation line along with the crack face with grain boundaries

Further to this, high temperature etching was carried out which revealed phosphorus segregation. 3D segregation mapping indicated concentrated patches of phosphorous compounds forming a continuous bands/lines along the rolling direction significantly at the quarter line portion. This segregation of phosphorus is observed to form between columnar and the equiaxed zone during casting (concluded based on the distinct segregation pattern of high temperature etching in the transverse section) (Fig 10 and Fig 11).

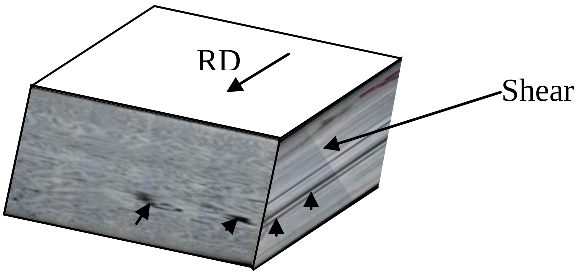


Fig 10 – 3D schematic of segregation of Phosphorus revealed through customized etching

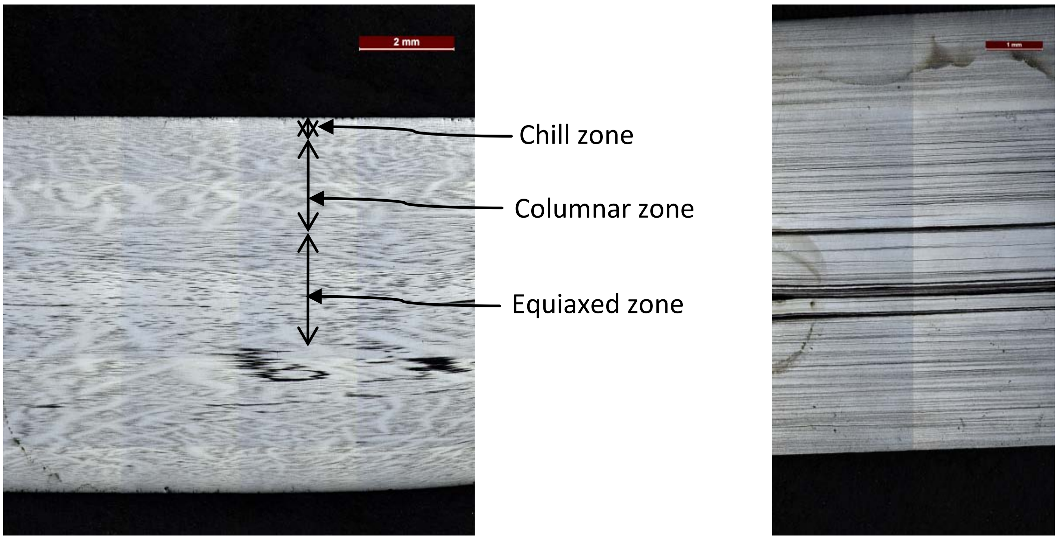


Fig 11 – Customized etching revealed segregation of Phosphorus in the material

4. DISCUSSIONS

In both the cases while the failure reasons were different, it was the technique of characterization which was the differentiator in arriving at the root cause of the failures. Normal etchant used could not divulge the reason as such.

In Sample 1 intended for high strength long member auto component,

- Microstructural observation across the crack revealed presence of banded structure involving fine grains, coarse grains and centreline segregation. This was only revealed after etching with hot picric acid. Micro-hardness study revealed brighter bands are having higher hardness than darker ones. Difference of hardness was around 30 HV within the same area of investigation.

- SEM observation revealed presence of higher amount of precipitates in brighter location than darker one though amount of fine grains were relatively higher in dark portions. The reason of this needs to be delved more.

- Crack surface was found to be parallel to the path of banding

- While the crack initiated in some pre- existing cracks due to shear at the edge, it propagated along this banded structure revealed otherwise through the customized etchant and temperature of etching.

- Controlling this banded structure or segregation either during casting or through homogenization during reheating could reduce this phenomenon.

In Sample 2 intended for brake auto component,

the authors could conclude that cracking phenomena in regular C-Mn grade for brake application during shearing has a relation with P segregation. P segregation pattern revealed heavy amount of P adjacent to the crack / separation line. Previous observations for medium C-Mn grades revealed pearlite banding / MnS as an initiator of such cracks under normal etching techniques but this study established a connection with phosphorus in this regard. Key findings of this study can be listed as below:

- MnS was not causing cracks during shearing operation
- An unknown phase along the crack line which was concluded to be a iron phosphide after color etching, micro-hardness and EDS analysis was found to be a primary reason to cause such cracking.
- Segregation study revealed that this P segregation was at interface of equiaxed and columnar zone which contributed to cracking/ separation.
- Controlling P segregation during casting based on correlation with casting parameters could improve the performance of these C-Mn grades.

5. CONCLUSION

- Normal Nital etch failed to reveal segregation bands and grain boundaries in a high strength structural steel auto component, while high temperature picral etch revealed grain size variation including banding emanating from segregation effects during casting.
- Normal Nital etch in a structural steel grade revealed whitish ferrite band type structure without grain boundaries. Micro-hardness however did not confirm it to be that of ferrite perplexing the cause of failure. Customized etchant based on picral and sodium thiosulphate combination at high temperature revealed grain boundaries of a unique phase which was confirmed to be that of phosphorus through EDS analysis.
- When conventional techniques fail to reveal the root cause of any cracking phenomena in high strength automotive steel, it is imperative to try out customized etching technique. This could reveal segregation or banding phenomena related to grain size variation, precipitation and phosphorus segregation as a reason of failure.

REFERENCES

1) ASTM Metal Hands book Vol 9

2) Internet matter – World Auto Steel

3) Internal Investigation Reports

4) Precipitation Behavior of Phosphides in the Centerline Segregation Zone of Continuously Cast Steel Slabs, Kurosawa et al, Materials Transaction, Vol 31

5) Etching and Image Analysis of Prior Austenite Grain Boundaries in Hardened Steels, Brewer et al, Materials Characterization, 27, 1991

6) Interaction between Phosphorus Micro-Segregation and Sulfide Precipitation in Rapidly Solidified Steel—Utilization of Impurity Elements in Scrap Steel, Liu et al, Materials Transactions, Vol 48, no 12, 2007

7) Revealing Prior Austenite Grain Boundaries, V Voort

8) Detecting non-uniform phosphorus distribution in ancient Indian iron by color metallography, Piccardo et al, Current Science, Vol 87, 2004

Effect of Boron on Forming Behaviour of Low Carbon Unalloyed Steel

Anjana Deva[1], Saikat K De[1], A Verma[2], B Mishra[2], S Roychowdhury[2], AK Bhakat[1], A Saxena[1] & BK Jha[1]
[1]R & D Centre for Iron and Steel, Steel Authority of India Limited, Ranchi- 834002, India
[2]Bokaro Steel Plant, Steel Authority of India Limited, Bokaro-827011, India
Email: anjana@sail-rdcis.com

Low carbon steel sheets used for auto industry, are required to have excellent drawability, ductility and non aging properties. Conventionally, boron is added to improve the hardenability of quenched and tempered steels. However, stoichiometric boron addition in low carbon Al-killed steel has been found to improve forming and cold reducing properties of hot rolled steel as a result of coarsening of ferrite grain size mainly due to substitution of coarse BN for AlN and also due to reduction of dissolved nitrogen and carbon in steel.

In present work, role of boron in low carbon Al killed cold rolled batch annealed steels is critically examined. It is found that B/N ratio is critical for forming properties not the absolute boron. Pancake shaped grains are desirable for achieving favourable {111} texture, normal anisotropy and drawability of the steel sheets. Micro structural analysis showed that the extent of pan caking increases with increase in B/N atomic ratio (upto 0.3) and then start decreasing leading to formation of equiaxed grains. Therefore, it can be inferred from this study that B/N ratio of 0.3 is the most optimum value for maximum pancaking and thereby, high plastic anisotropy ratio (r_m). The desirable orientation in steel with low B/N ratio is attributed to sufficient availability of Al and N to precipitate during batch annealing. This study will be helpful in development of cold rolled batch annealed formable steel even with higher nitrogen content (upto 80 ppm).

Keywords: Low Carbon Steel, Boron, Batch Annealing, Forming Properties, Texture

1 INTRODUCTION

Formability of hot rolled steel is characterized by lower yield strength, low YS / UTS ratio, high elongation, high strain hardening exponent (n) and low strain aging index (SAI). It is seriously impaired by nitrogen dissolved in ferrite[1,2] which can be counteracted by optimized temperature management in the hot strip mill in case of aluminium (Al) killed steel. However, with the high coiling temperature necessary for nitrogen fixation, a limited degree of uniformity of the mechanical properties over the length of strip as well as unfavourable pickling behaviour is expected. In the study by Muschenborn et al.[3], it has been shown that titanium or boron addition improves the formability of hot rolled steel as a result of nitrogen fixing. Although titanium has been extensively used to tie-up nitrogen, potential of boron for this purpose has not been fully exploited. Cho and Kim[4] in their recent work have studied the effect of boron addition on the microstructure and mechanical properties of as hot rolled unalloyed low carbon (0.02-0.04 wt. %C) steels. Conventionally, low carbon steel sheets have been produced by batch annealing after cold rolling. Study on continuous annealing of low carbon Al-killed steel has been carried out by many researchers[5-9] where the importance of carbon and nitrogen in solution in influencing elongation and plastic anisotropy ratio (r_m) value has been highlighted. Although boron has beneficial effect on the forming properties of continuously cold rolled (CR) steel, only a few work[10, 11] has been carried out on its role in batch annealed CR steel.

Quinto et al.[10] carried out extensive study on the role of boron in low carbon (0.07 wt. %) unalloyed steel processed through batch annealing route. They have observed that addition of more than 15 ppm of boron to Al-killed drawing quality steel reduces its drawing properties to that essentially of rimmed steel. The change of r_m value from 1.7 to 1.2 is associated with characteristic change from elongated to equiaxed ferrite grains, an inhibition of aluminium nitride precipitation in annealed sheet and lowering of intensity of {111} poles. They have reported that AlN precipitation, which is critical to the development of texture, is inhibited by boron additions to such an extent as to nullify its effect in aluminium killed steel. However, the mechanism by which boron acts to retard AlN precipitation has not been explained. Precipitation of AlN can be affected by changes in relative activities of solute elements involved, by competing with other precipitation favoured by thermodynamic or kinetic factors, which govern the ease with which certain precipitates can be nucleated. Since boron modifies cementite precipitation, it is interesting to observe that carbon percentage has an effect on AlN precipitation. Ichiama et al.[11] have shown that increasing carbon levels from 0.002 to 0.01 in Fe-Al-N alloys accelerates AlN precipitation. This is presumably because the coexisting carbon atoms reduce solubility of nitrogen and the fine cementite particles furnish more sites of AlN precipitation.

In a recent study[12], it has been reported that the non-availability of nitrogen to precipitate as AlN is the principal reason for low rm value in Al-killed batch annealed steel which is not in line with the work of Quinto et al.[10]. Effect of B/N atomic ratio on the forming behavior of low carbon batch annealed aluminum killed steel has clearly demonstrated that B/N ratio can be optimized. Sufficient nitrogen is available in solution to combine with aluminium during batch annealing so that lower yield strength, higher elongation and almost similar r_m value are obtained in boron added steel which is similar to those observed in boron free steel. Advantage of this study can be exploited in development of cold rolled batch annealed formable steels even with higher nitrogen content.

2.0 EXPERIMENTAL

A systematic study was carried out with varying B/N ratio from 0 to 1. Several industrial heats were made and processed at Bokaro Steel Plant through basic oxygen furnace (BF) – ladle furnace (LF) – continuous casting (CC) – hot strip mill (HSM) route into 2.8 mm thick hot rolled coils. While comparing the mechanical properties, interesting results were found in terms of tensile and forming properties. The chemical composition of steels used for this study is shown in Table 1. It may be noted from Table 1 that steel A is the typical chemistry of low carbon boron free steel, whereas in other eight steels B/N atomic ratio varied from 0.15 to 0.87. Other elements were controlled in industrially close ranges.

Table 1 Chemical Composition (wt. %) & B/N atomic ratio of steels

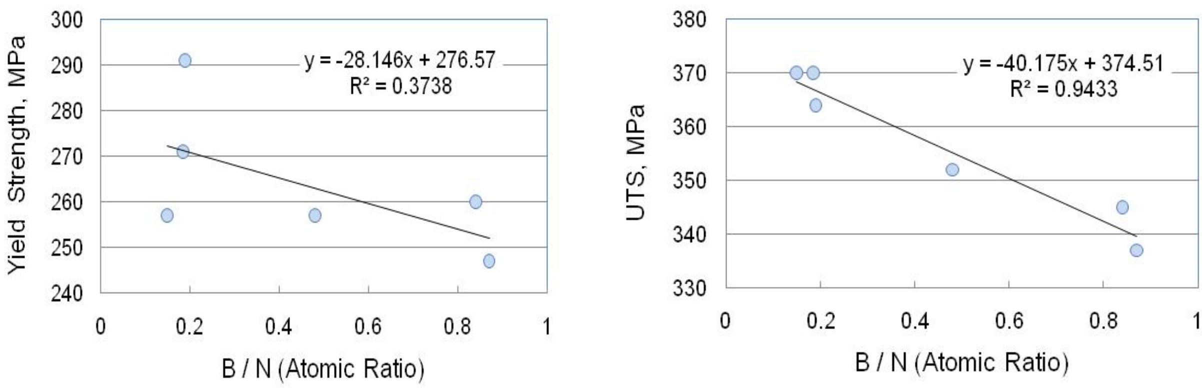
Steel	C	Mn	S	P	Si	Al	B*	N*	B/N[#]
A	0.030	0.16	0.007	0.013	0.027	0.038	0	57	0
B	0.032	0.16	0.009	0.012	0.038	0.015	10	84	0.15
C	0.034	0.17	0.005	0.015	0.029	0.030	12	84	0.185

D	0.035	0.16	0.010	0.013	0.037	0.016	10	68	0.19
E	0.038	0.18	0.006	0.015	0.036	0.023	20	85	0.30
F	0.037	0.18	0.008	0.017	0.019	0.031	20	54	0.48
G	0.036	0.18	0.007	0.015	0.032	0.034	20	40	0.64
H	0.032	0.17	0.009	0.014	0.025	0.015	52	80	0.84
I	0.033	0.17	0.009	0.014	0.032	0.041	45	67	0.87

* ppm # Atomic Ratio

2.1 Industrial boron free and boron added low carbon hot rolled steel

The effect of boron (in terms of boron to nitrogen atomic ratio) on hot band strength level is illustrated in Fig. 1 (a & b). Increasing the ratio resulted in drop on both yield and tensile strength, whereas not much difference in percentage elongation is observed. Decrease in YS and UTS values with increase in B/N ratio can be attributed to decrease in solute nitrogen in steel and increase in grain size.

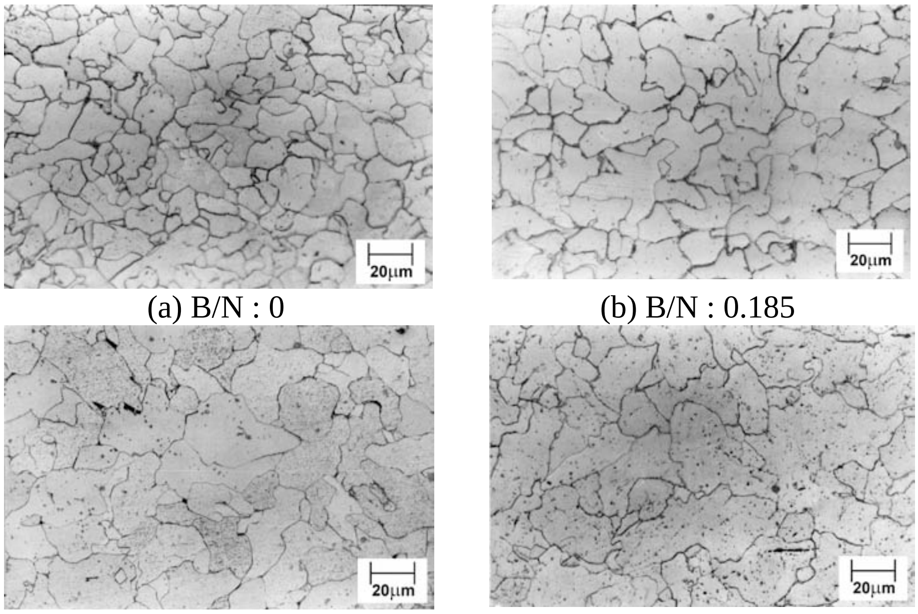


(a) **(b)**

Fig 1 B/N ratio & (a) Yield Strength (b) Ultimate Tensile Strength

2.2 Boron / Nitrogen ratio and microstructure

Fig 2a shows optical microstructure of boron free steel, the ferrite grain size of which is 11.5 µm. At the atomic ratio (0.185) of B/N, the average ferrite grain size (Fig 2b) becomes coarser (18 µm) as compared to that of boron free steel. Increasing the ratio further resulted in further coarsening of ferrite grain size, which is revealed in Fig 2 c & d. This can be attributed to precipitation of coarse BN in preference to fine AlN. Ferrite grain size at each B/N ratio was measured and a plot (Fig 3) is generated while correlating these two factors, a straight line confirms a good correlation co-efficient (R^2) of 0.936.



(a) B/N : 0 (b) B/N : 0.185

(c) B/N : 0.48 (d) B/N : 0.87

Fig 2 Optical micrographs of steel with different B/N ratio of (a) 0 (b) ~ 0.2 (c) ~ 0.5 and (d) ~ 0.9 at coiling temperature of 570 $\pm$ 10 ^{o}C

Many researchers[5,7,13,14] have worked to exploit the change in microstructure of the hot band by adding boron for obtaining improved forming properties of continuous annealed steel sheet. Takahashi and his co-workers[7] aim was to promote the growth of recrystallised ferrite grains within a short span of annealing time by producing the coarser precipitate sizes which are unable to inhibit growth of grain during continuous annealing. Increase in the boron addition, at first, resulted in a drop of both yield and tensile strengths, with a minimum strength for a B/N ratio in the range of 0.8 to 1.0.

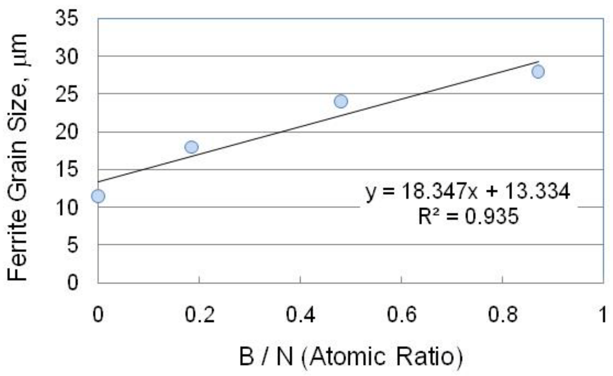


Fig 3 Effect of B/N atomic ratio on grain size

A further increase in the boron content, however, increased the strength level. Sudo and Tsukatani[15] have found that soluble boron was almost zero for B/N of less than 0.5. This implies that almost all boron in the sheets having a B/N of below 0.5 was precipitated as BN. Soluble boron increased sharply with increasing B/N above 0.5 and the peak ferrite grain size of hot bands was obtained in the steel containing soluble boron of 10-15 ppm. This implies that soluble boron of this amount is necessary to decrease the ferrite nucleation site during transformation from austenite to ferrite. It has been established that 5-20 ppm of boron segregates to austenite grain boundaries and retard nucleation of ferrite and bainite in low carbon steels[16].

The change in grain size accompanied by the change in boron content was considered to be affected by precipitates. Pradhan[5] and Takahashi[17] both in their work affirmed that increasing ferrite grain size upto B/N of 0.8-1.0 range was because (a) unlike the fine AlN, the coarser BN particles do not inhibit growth of the recrystallised ferrite grain during rapid annealing (about 1 minute) and (b) grain size of the parent hot rolled material became increasing coarser. By substituting large BN for AlN, grain growth tendency improves which results in higher total elongation.

2.3 Industrial boron free and boron added low carbon cold rolled steel

The hot rolled (HR) bands with varying B/N ratio of 0 to 1 were cold reduced to 1.2 mm thickness and were annealed with the standard longer annealing cycles used for low carbon extra deep drawing grade steel in steel plant as schematically shown in Fig 4. Intermediate holding at 550°C has been intentionally kept to facilitate maximization of AlN precipitation before recrystallisation.

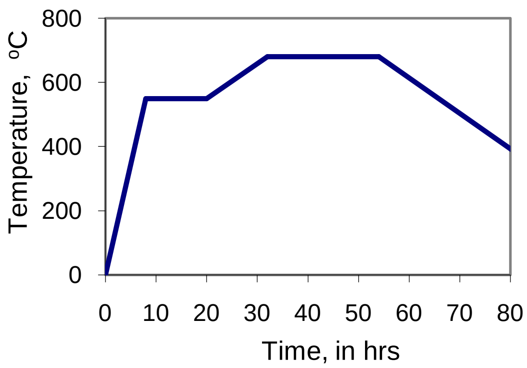


Fig 4 Schematic representations of batch annealing cycle

Micro structural observations were performed on polished and etched (2-4 % nital) hot rolled and cold rolled annealed samples. All the strips were observed in a plane perpendicular to the rolling plane and along the rolling direction. The major and minor axes for individual grains for all the cold rolled batch annealed samples were measured to determine aspect ratio using image analyzer Leica 600. Mean plastic anisotropy ratios (r_m) were measured for aspect ratio of 1.82 and 3.75 and having B/N ratio 0.87 and 0.185 respectively.

In addition to the grain size, grain shape is known to strongly influence the properties of cold rolled batch annealed steel[18]. For example in the aluminum killed grade steel, pancake shaped grains (high grain shape anisotropy) are highly desirable for improving the desirable {111} texture, normal anisotropy and drawability of the steel sheets[19]. In the current study the grain shape anisotropy has been characterized through grain aspect ratio, which is the ratio of major and minor grain length. Fig 5 shows the variation of aspect ratio with varying B/N atomic ratio.

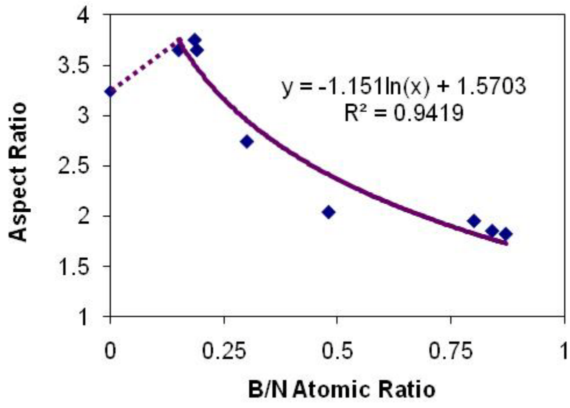
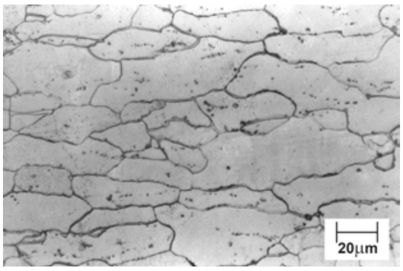


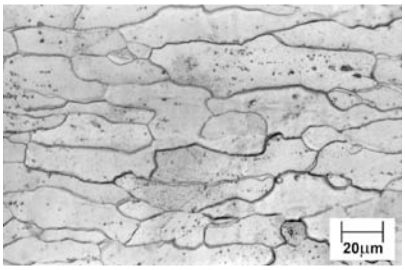
Fig 5 Variation in mean aspect ratio with varying B/N atomic ratio

It is interesting to note that aspect ratio of steel B (B/N: 0.185) is found to be higher (shown by dotted line) as compared to that of steel A (B/N: 0). As the B/N ratio increases, aspect ratio decreases. A definite logarithmic trend emerged while co-relating B/N ratio vis-à-vis aspect ratio, showing a good correlation coefficient (R^2 = 0.94).

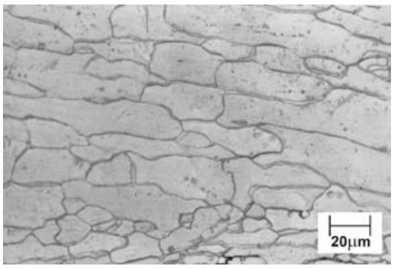
The change in microstructure from pancaking to equiaxed with increasing B/N ratio has been shown in Figs 6 (a - f). As is evident, the extent of pancaking has decreased with increasing B/N ratio, and it is equiaxed in steel with B/N of 0.87. Deep drawing aluminum killed steels are processed keeping low coiling temperature leaving Al and N in super saturated solid solution. AlN particle or AlN clusters precipitate at the early stage of batch annealing at the boundaries of sub grain in the deformed samples[18, 19]. The dominant effect of these clusters or precipitate is to retard nucleation of recrystallisation.



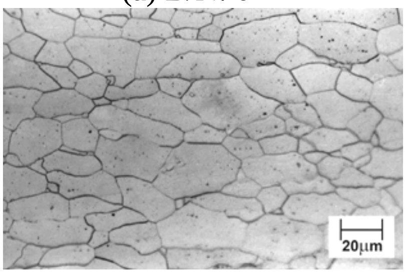
(a) B/N: 0



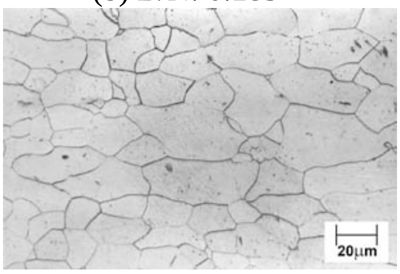
(b) B/N: 0.185



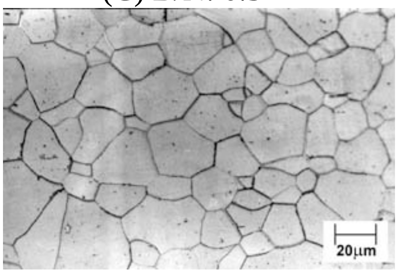
(C) B/N: 0.3



(d) B/N: 0.48



(e) B/N: 0.64



(f) B/N: 0.87

Figs 6 (a - f) Microstructure of cold rolled batch annealed steel with increasing B/N ratio

More precisely nucleation by sub grain growth is selectively inhibited by these clusters or precipitate at sub grain boundary[18]. At the end of batch annealing treatment, the pancake grains are a consequence of the initial pancake deformed microstructure and the precipitation of aluminum nitrides in sheets on prior grain boundaries and sub boundaries which lies in the rolling plane, therefore providing anisotropy barrier to growth[18, 19]. The pancaking behaviour of microstructure has also been found in boron added steel (Fig 6 b-d), which is an indirect evidence of presence of sufficient Al and N in super saturated solid solution during batch annealing. With increase in B/N ratio, the extent of pancaking decreases and tends ultimately to formation of equiaxed grains (Fig 6 e & f).

2.4 Effect of Boron /Nitrogen ratio on texture evolution

Figs. 7 a & b shows the XRD scan results as plots of intensity vs. 2θ angle. Intensity peaks of (110), (200), (211), (220), (310) and (222) planes of ferrite are observed at their characteristics angles as indexed. Intensity of (222) and (110) is more in case of steel having pancaked microstructure when compared with those of equiaxed microstructure (Figs 7 a & b). XRD results indicate 1.9 times higher value of (111) / (100), for steel with 0.185 B/N ratio (which is desirable for better r_m value) compared to that of steel with B/N ratio of 0.87.

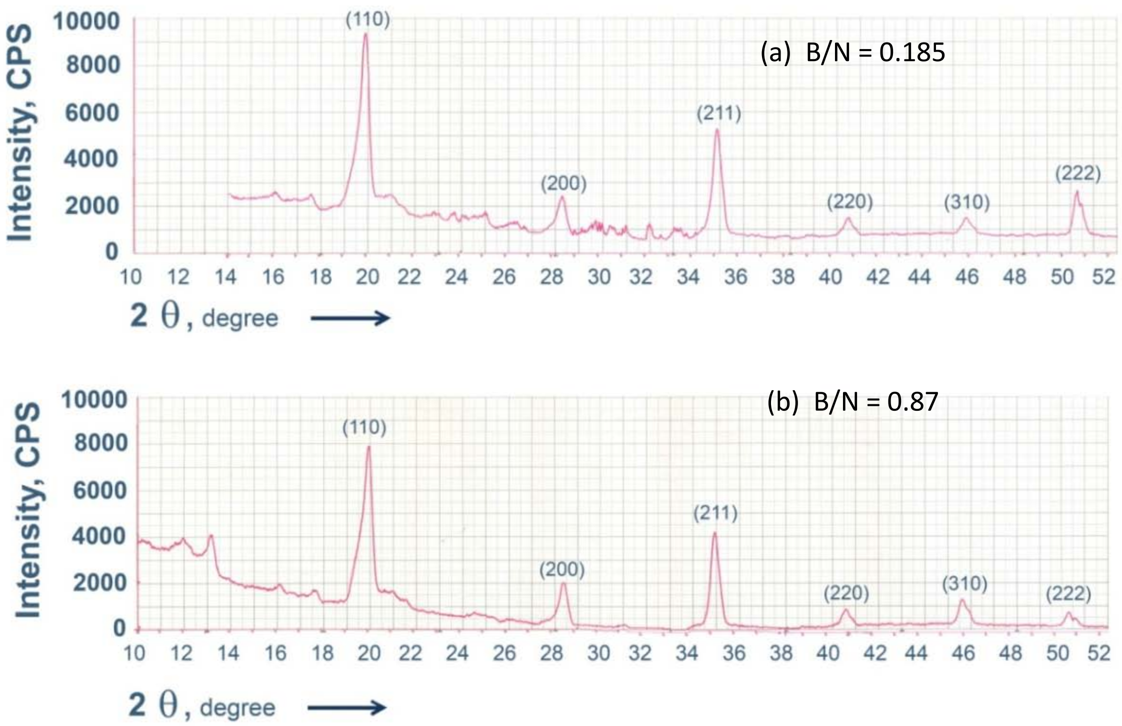


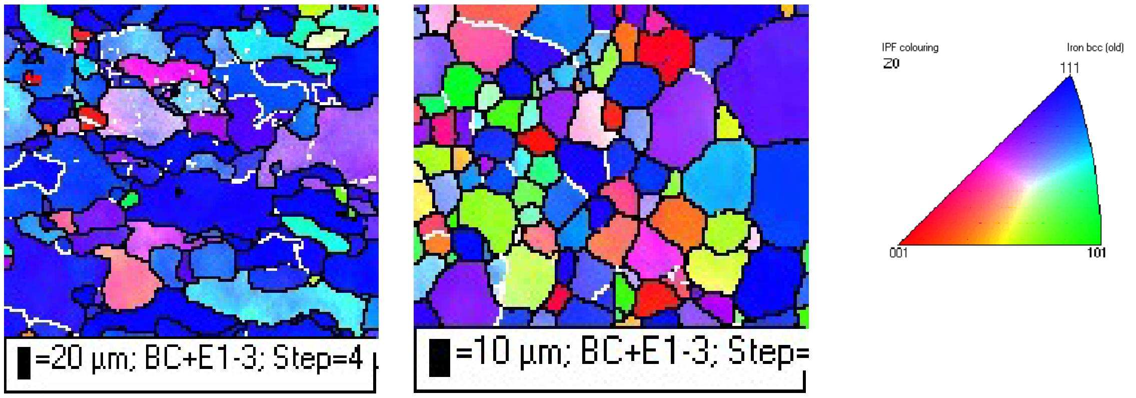
Fig 7 XRD analysis of boron added cold rolled batch annealed steels having (a) pancaked and (b) equiaxed microstructure

2.5 Micro-textural analysis

Further to understand the textural evolution in steel samples with B/N ratio of 0.185 and 0.87, samples were analyzed through EBSD. Figs. 9 a & b represent Inverse Pole Figure

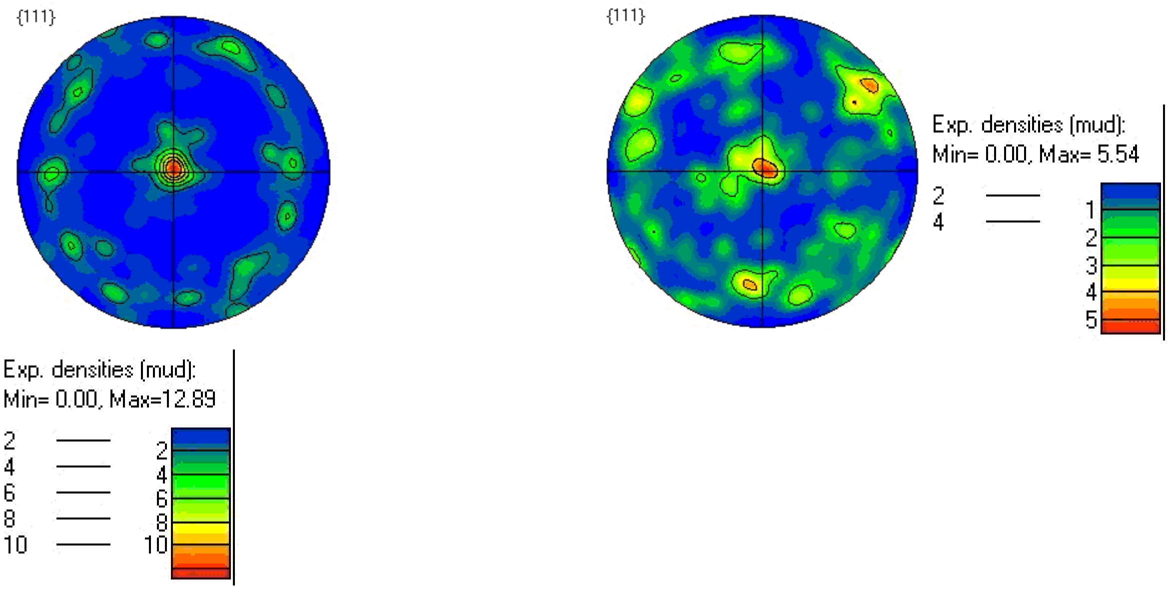
(IPF) map of pancaked and equiaxed microstructure, in which the colours correspond to the crystal orientations as shown in the projection. Unit triangle of the inverse pole figure showing the alignment of crystal in relation to the rolling direction is shown in Fig. 9c.

For Grain boundary calculation, mis-orientation of 15 degree was kept as cut-off between low- and high-angle boundaries. Between 3 and 15 degree are considered as low-angle boundaries (i.e. sub-boundaries) given in white boundaries and above 15 degrees are considered as high-angle boundaries (i.e. grain boundaries) in black boundaries. Below 3 degree, was considered as in-grain mis-orientation and was not considered for grain boundary calculation. It is evident from the colour contours that undesirable texture for forming properties (001) has grown at the expense of (101) texture in sample with B/N ratio of 0.87. This finding corroborates the XRD results.



(a) IPF for pancaked structure (b) Unit triangle (c) IPF for equiaxed structure

Fig 9 Inverse Pole Figure (IPF) map

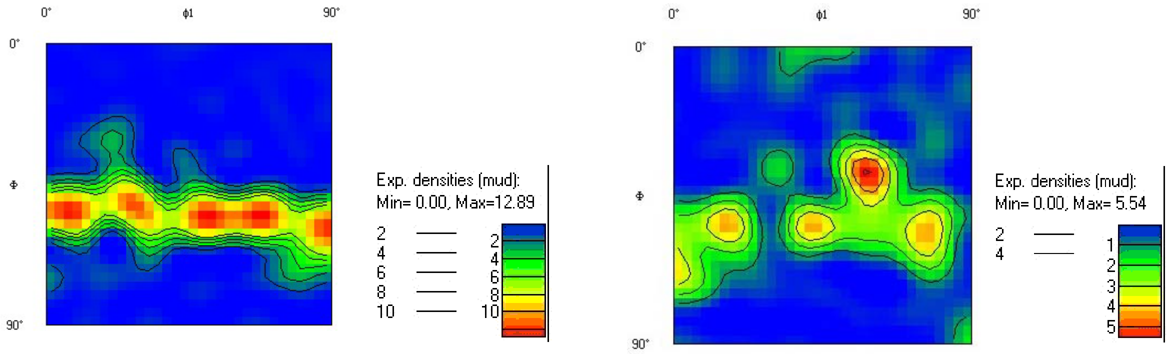


(a) For steel with pancaked stucture (b) For steel with equiaxed structure

Fig 10 Pole figures

Figs. 10 a & b show Pole Figure (PF) for the steels with pancaked and equiaxed structures whereas Figs. 11 a & b depict Orientation Distribution Function (ODF) visualised through φ2 = 45 degree section for the same steels.

It is apparent from ODF results that the major texture components in steel with equiaxed microstructure are the alpha (α) fibre {001} <110> to {111} <110>, whereas it is predominantly gamma (γ) fibre {111} <110> to {111} <112> in steel with pancaked structure.



(a) For steel with pancaked stucture (b) For steel with equiaxed structure

Fig 11 $\phi_2 = 45^o$ section of ODF

Preliminary analyses of the results are in line with the findings of Hutchinson et al. [19] and Ray et al. 20 wherein recrystallisation of deformed ferrite has resulted in strengthening of γ fiber and thereby improvement in plastic anisotropy ratio (r_m). Gamma fiber covers all components between {111} <110> to {111} <112>. In order to be a highly deep drawable material high proportion of grains must be oriented with their {111} planes parallel to their sheet plane, as found in the present study. Textural analysis through XRD and EBSD supports the conjecture discussed above highlighting the importance of available Al and N in solution for development of favourable texture.

3.0 Conclusion

Addition of boron in low carbon Al-killed hot rolled steel resulted all round improvement in formability and cold rollability. Increase in B/N ratio led to decrease in yield and ultimate tensile strength values and increase in grain size. Unique combination of strain hardening exponent and uniform elongation has been established. Lowering of n value and improvement in ductility has been correlated with change in carbide precipitation site, dislocation precipitate and dislocation grain boundary interaction.

Effect of B/N atomic ratio influenced the forming behavior of low carbon batch annealed aluminum killed steel also. It has been concluded B/N ratio that controls the properties of batch annealed aluminum killed steel rather the absolute boron. Availability of Al and N in solid solution was found to be the main governing factor for its precipitation during batch annealing even if boron is present in steel. B/N of 0.3 resulted in lower YS, higher elongation and almost similar r_m value in boron added steel as compared to boron free steel. Optimum amount of boron, nitrogen and aluminum can lead to coarse pancake structure ideally suited for improved formability.

REFERENCES

1) De S. K., Deva Anjana, Mukhopadhyay S., Mallik S., Verma S. and Jha B. K., Steel Times International, April 2009, Vol. 33, No 3, p.53.

2) Bleck W., Kohler K., Meyer L. and Preisendanz C., Thyssen Techn. Ber., 1991, Vol.23(1), p. 43.

3) Muschenborn W., Imlau K.P., Meyer L. and Schriever U., Micro-alloying 95 Conf. Proceeding, 1995, p.35.

4) Cho Y.R. and Kim S.I., Iron and Steel Technology, May 2004, p.46.

5) Pradhan R., Conf. Proceeding on Technology of Continuous Annealed Cold Rolled Sheet Steel, TMS-AIME, Warrandale, PA, 1984, p.185.

6) Funakawa Y., Inazumi T. and Hosoya Y., ISIJ International, 2001, Vol. 41, No. 8, p.900.

7) Takahashi N., Abe M., Akishu O. and Katoh H., Conf. Proceeding on Metall. of Continuous Annealed Sheet Steel, TMS-AIME, Warrandale, 1982, p.51.

8) Hosoya Y., Kobayashi H., Shimumura T., Matsudo K. and Kurihara K., Conf. Proceeding on Technology of Continuous Annealed Cold Rolled Sheet Steel, TMS-AIME, Warrandale, PA, 1984, p.61.

9) Kawamura K., Otsudo T. and Furukawa, Trans ISIJ, 1976, Vo.16, p.538.

10) Quinto D.T. and Hughes I.F., Metallurgical Transactions, 1976, Vol. 7A, p.165.

11) Ichiyama T., Koizumi M., Yoshida I., Watanabe K. and Nishiyumi S., Transactions ISIJ, 1970, Vol. 10, p.429.

12) Deva Anjana, De S. K. and Jha B. K., Material Science and Technology, 2008, No.1, p.124.

13) Takahashi N., Foruno Y., Nosaka S., Fukuchi T., Asai T. And Awamoto T., Transaction ISIJ, 1980, Vol.20, No 10, p.B451

14) Takahashi N., Foruno Y. and Hayakaw T., Trans ISIJ, 1981, Vol.21, No.6, p. B286.

15) Sudo M. and Tsukatani I., Conf. Proceeding on Technology of Continuous Annealed Cold Rolled Sheet Steel, TMS-AIME, Warrandale, PA, 1984, p.203.

16) Bhadeshia H. K. D. H. and Svensson L. E., International conference proceeding on modeling and control of joining process, edited by Zacharia, American Welding Society, p.153.

17) Takahashi N., Furuno Y. and Hayakawa H., ISIJ, 1980, B-286, Lecture No. S1247.

18) Sahay Satyam S., Kumar B. V. H. and Krishnan S. J., Journal of Materials Engineering and Performance, 2003, Vol.12, p.701.

19) Hutchinson W. B., International Metal Reviews, 29(1984) No. 1, p.25.

20) Ray R.K., Jonas J.J., and Hook R.E., International Materials Reviews, 39 (1994) No. 4, p. 129.

Automotive Steel Production- Quality Improvement Initiatives in Continuous Casting

Anupkumar Nandakumar
Vesuvius India Ltd, Kolkata, West Bengal-700088, India
Email: Anupkumar.Nandakumar@vesuivus.com

Automotive Industry is in a growth track in India and is trying to catch pace with rest of the world. While this industry is preferring imported steel for their critical applications, Indian Steel makers are gearing up to position themselves as reliable and cost effective alternative in desired quality steel to the automotive Industry. The paper is indented to highlight the areas which impact the Steel cleanliness and yield improvement, Tundish – Mould.

An attempt has been made to explore the impacts, taking references of the success at various steelmakers, with in India and abroad. The paper covers smart technologies that help reduction of the Steel re-oxidation and convert more steel in to prime quality thereby increasing productivity. Another area which helps the improvement of the steel quality by means of Inclusion floatation before it actually reaches the mould is included from a case study. A study of specially designed Subentry nozzle also has been included in the study to evaluate the effect on the sub meniscus velocity, the mould slag entrapment in the cast product. In addition to this some of the niche technologies developed in order to meet the above objective of Steel Cleanliness and yield enhancement which is prime importance in making automotive grades.

Continuous casting process improvement plays a major role in ensuring the right quality of steel.

Keywords: Tundish Furniture, Subentry Nozzle, Re-Oxidation, Mould Slag Entrapment, Bell Shroud, Extended Shroud, Submerged Opening, Steel Cleanliness, Yield Enhancement, Tundish Gas Diffuser

1. INTRODUCTION

Steel is an intrinsic part of the automobile. The steel making industry is continuously driving it towards making steel which is lighter and stronger. Interstitial Free grades (ULC) is a result of the search in this direction by the steel makers. The major issues concerning production of these grades include and not limited to Cleanliness, Clogging, Continuous casting mould meniscus stability and Yield enhancement. In each of the issues mentioned, Tundish plays a vital role. Each of these are interlinked to an extent. An attempt is done to collate the same. The issues listed may be tackled by using some of the engineered solutions, at least a reduction to that effect can be seen in the later sections. Fig 1, shows a schematic of the various furniture configurations that could be used in a tundish.

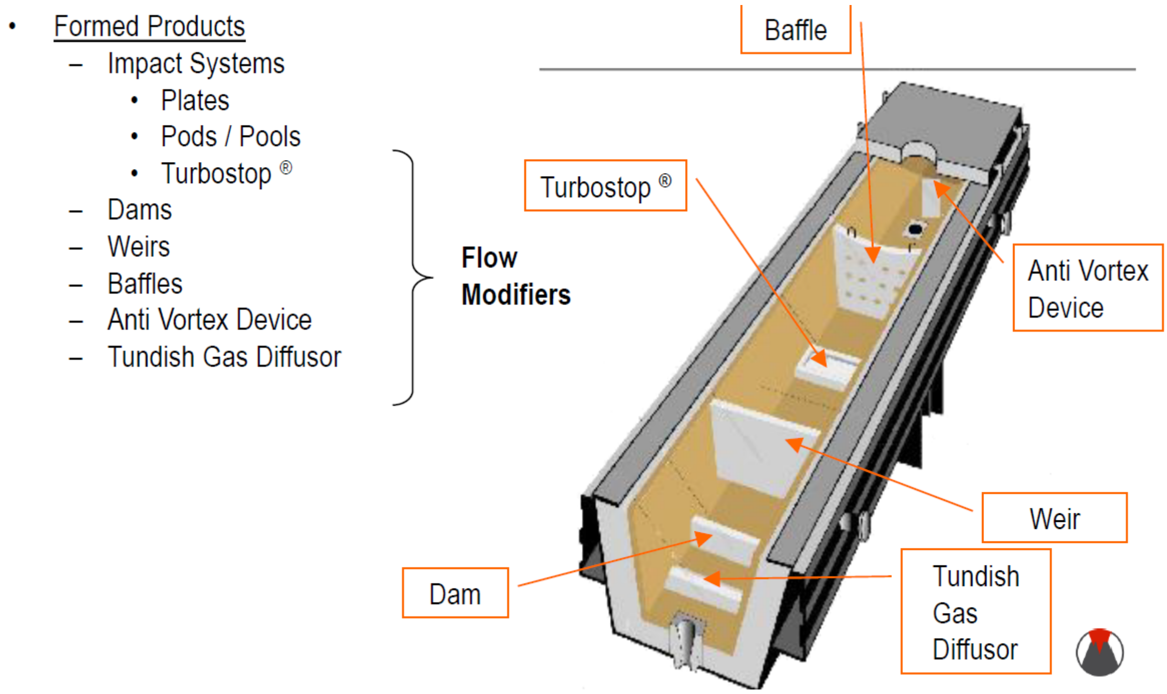


Fig 1 Tundish & Furnitures

2. STEEL CLEANLINESS

Clean steel production involves the fluid flow stability inside the tundish. The function of the tundish basically is a holding vessel for continuous casting. It's important that chemical and temperature homogenization is obtained, inclusions are floated out before it find the way out of in to the mould and the distribution of the metal flow is well directed.

The fluid flow is influenced by the following factors as seen from CFD analysis.

- The shape of the tundish
- The casting rate
- Ladle shroud positioning, design, diameter, immersion depth and gas injection
- The tundish furniture.

The rational for considering the flow dynamics include the kind of variations that are involved in an operating plant which can only be minimized but not eliminated completely. Other than that, the reasoning why the flow dynamics is important may include and not limited to, steady and unsteady conditions: Tundish filling, refilling and steady levels, Purity of the steel: Inclusions and surface defects, Erosions in the tundish and refractories and thermodynamic factors – Cold and hot areas

Fig 2a) Schematic of the Tundish slag emulsification, Fig 2b) A water model of tundish depicting the slag emulsification at the pouring area.

The Flow in to the tundish starts at the outlet from the ladle shroud in to the Tundish. The immersion of the Ladle shroud inside the tundish plays a very important role in the steel cleanliness. A strong tundish slag re-entrainment especially during refill at low submergence can be seen as in Figures 2a and 2b. Use of a flow modifier special impact pads helps direct the flow upwards towards the surface around the ladle shroud. The schematic below in figure 3a reflects the same. The water model (Fig 3b) gives an idea about the reduction in emulsification by Tundish slag.

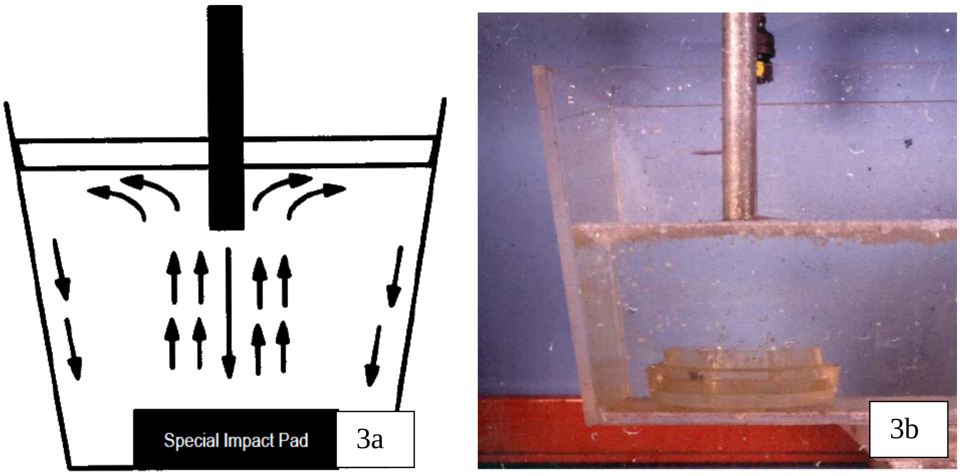


Fig 3a) Schematic of the upward push, Fig 3b) A water model of tundish depicting the very minimal slag re-entrainment.

The measure of total oxygen content in the tundish is a rough approximation of the cleanliness of the steel. A plant trial result shows the comparison of the total oxygen content with a regular impact pad vs the specially designed impact pads in Figure 4. The graphical plot shows the change in the total oxygen content during a sequence sampled at regular intervals. The spikes in the plot seen are correlated with the ladle changeover period.

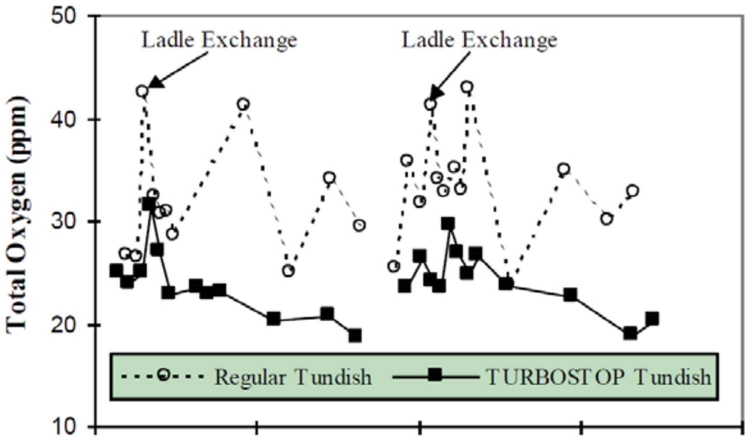


Fig 4 Comparison between a regular tundish impact pads vs. Turbostop™ in a sequence

The open area of the steel (uncovered portion in the surface) sees a reduction with the use of specially designed Impact pads. The more uncovered portion or red eye in the surface means, more reoxidation potential leading to increase in non metallic inclusions in steel. The contact from the atmospheric air needs to be kept as minimal as possible. This condition is very relevant at the start of casting where the tundish covering compound is added only after the stable meniscus is obtained. It will extend the duration for which the surface is protected from the atmospheric air. This will lead to a reduction of prime quality product produced because of the possible non metallic inclusions. Use of abell shaped shroud to increase the immersion at the beginning of the filling of tundish has seen to be beneficial in adding the tundish Flux at an earlier time (for submerged opening). The CFD study result is shown below depicting this effect in Fig 5a. This is equally applicable in ladle exchange time as shown by the data in in the Fig 4.

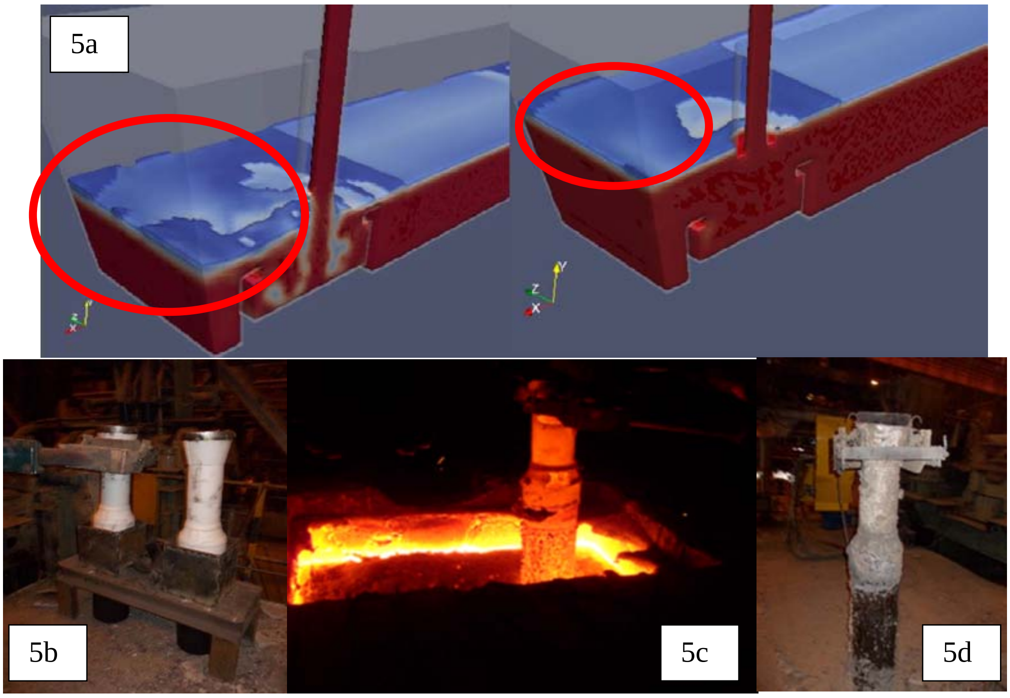
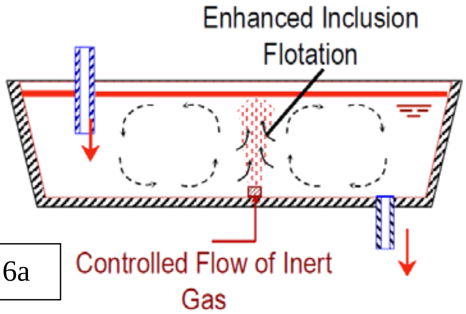


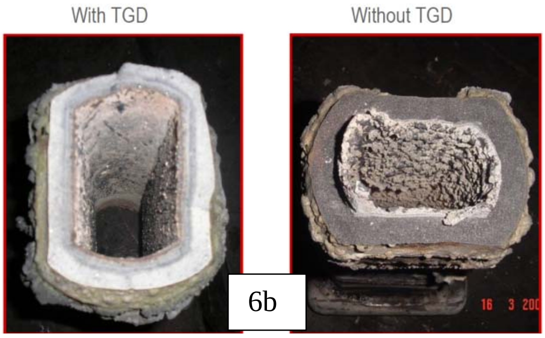
Fig 5a) Tundish on the left without submerged opening and one on the right is with the Bell shroud Fig 5b) Actual Bell shaped Ladle Shroud used in a caster before use with the manipulator Fig 5c) Bell shroud in use during a tundish refill Fig 5d) Bell Shroud after use

In Fig 5a on the left, the unsubmerged shroud shows the turbulence in the surface. It also shows the air entrainment while the tundish on the right shows more stable surface and consequently, less air entrainment, which is a cause for the reoxidation. In Fig 5c, it is also seen that there are no splashes or red eye formation while refill of tundish.

When it comes to cleanliness of steel, the separation of non- metallic inclusions in the tundish is very important. Analogically similar to the Ladle purging refractories, there are tundish purging refractories also available. The tundish gas diffusers help in facilitating inclusion floatation if used in the correct position in the tundish. It is used in conjunction with an active tundish flux for the capturing of these inclusions. In addition to this, the physical modelling lab experiments have shown that there is an increase in the mixed flow regions in the tundish. This tends to increase the temperature homogenization inside the tundish. The fixture of the tundish gas diffuser in the tundish with the potential increase in inclusion floatation is shown in the schematic and a mechanism of floatation in Fig 6a. However, the position of the TGD is important within he tundish to get the desired benefit. In Fig 6b, the field trial result showing the decrease in the clogging after same grade namely the ULC grade is shown. An example of the tundish gas diffuser fixed in the tundish is as shown in the Fig 7.



6a



6b

Fig 6a) Schematic of Tundish Gas diffuser fixed in a tundish. Fig 6b) Field trial depicting the difference in the clogging in the SEN with the use of Tundish gas diffuser and without

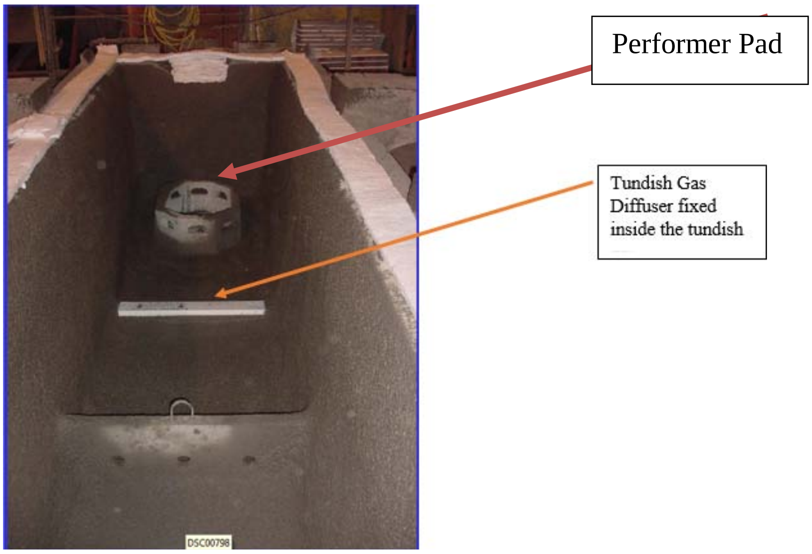


Fig 7 Tundish gas diffuser fixed inside the tundish.

3. MOULD FLOW STABILITY

The feeding of proper metal flow into the mould plays an important role in the quality of the product. It impacts the stability of the mould meniscus. An unstable meniscus tends to increase the mould slag entrapment in the cast product which in turn will remain in the finished product as a defect. The Tundish and the mould is connected with the SEN, and the flow control device namely stopper is used to control the feeding based on the casting parameters. When we consider a ULC grade, the chances of the improper delivery is even more because of the extent of the clogging in the SEN seat/ Stopper rod control area. Studies have revealed that the nose geometry of the stopper rod if designed properly can be of advantage. Plant trials have validated these aspects which is shown later in this section.

Surface defects in the solidifying shell are in general created in the meniscus and they remain unchanged as they move through the mould wall. The non-metallic inclusions (clog) attached to the SEN seat/ Stopper nose area could be detached from the nose surface and entrained in to the casting channel and in to the mould. This detachment is often referred to as 'Flushing' by steel makers. When flushing occurs, the physical gap increases in the mould between the strand and mould wall. This leads to an unplanned increase in liquid metal delivered in to the mould. Thus, a flushing is always followed by an increase in level fluctuation that can cause mould flux entrapment and steel overflowing the solidifying shell. This mechanism has been very well explained by Sengupta[1] as seen in Fig 8. In addition hook formation is observed in the slab surface [2].

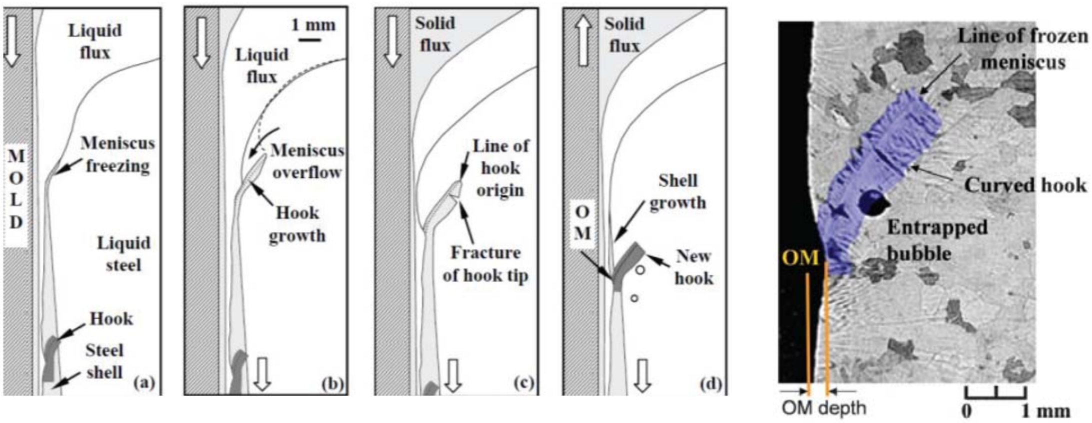


Fig 8 Schematic of hook formation [1]

The flushing as described above occurs when the minimum pressure is increased at the junction of the SEN seat and Stopper nose as described by Richaud J [3]. Fig 9 shows the change in detachment regions with the throughput. The Ripple Stopper™ is shown with the nose geometry designed through flow modelling in Fig 10. In comparison with the conventional stopper nose geometry, it also shows that there is reduction in the bias nature of flow in to the mould.

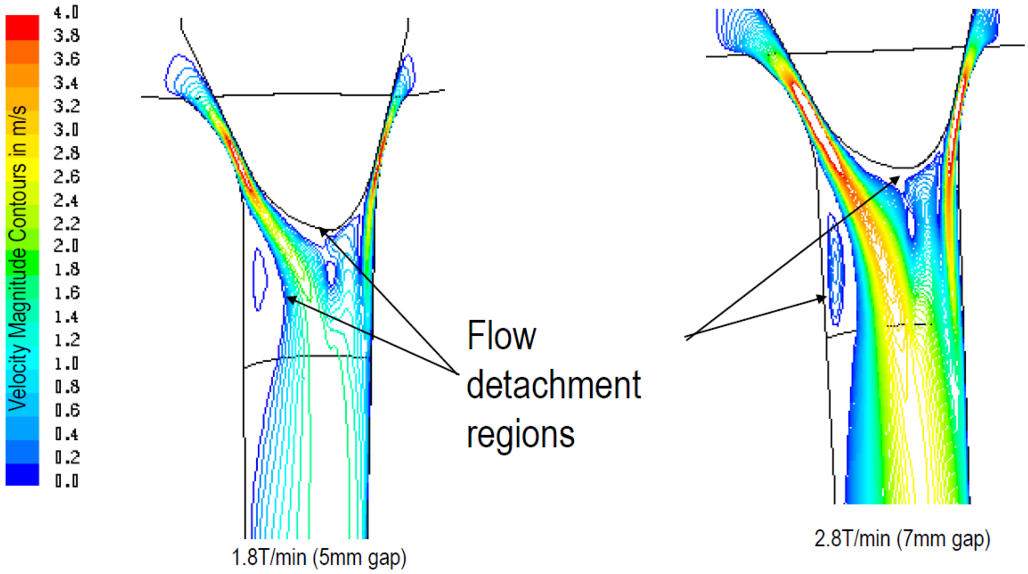


Fig 9 Detachment regions below the stopper nose.

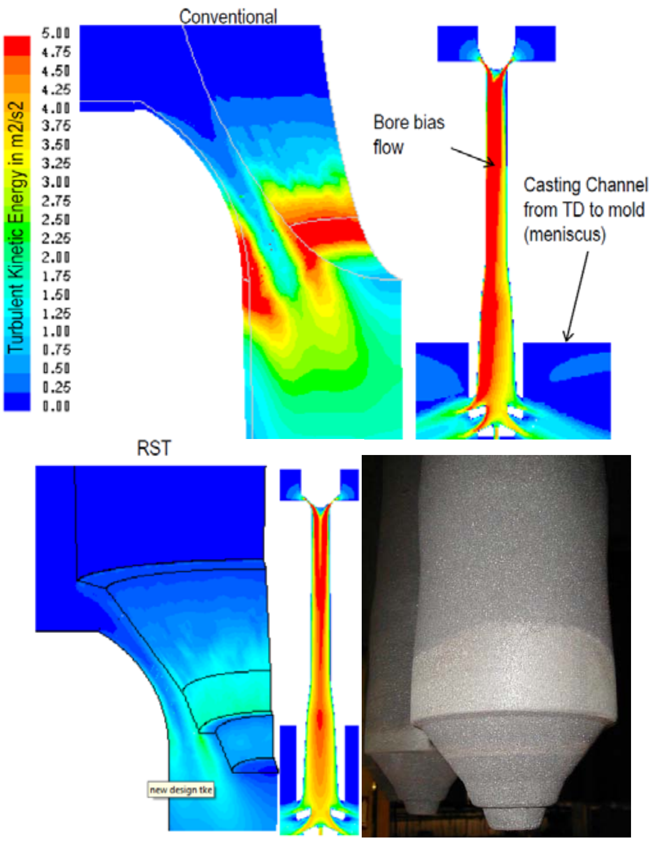


Fig 10 On the top, conventional stopper to mould CFD and in the bottom left it shows the unbiased flow from the Ripple Stopper™. Picture of an actual Ripple Stopper™ nose geometry on the lower right.

Field trial run to compare the mould level fluctuations reveal that the Ripple Stopper™ has reduced the level fluctuations significantly [3] as shown in Fig 11.

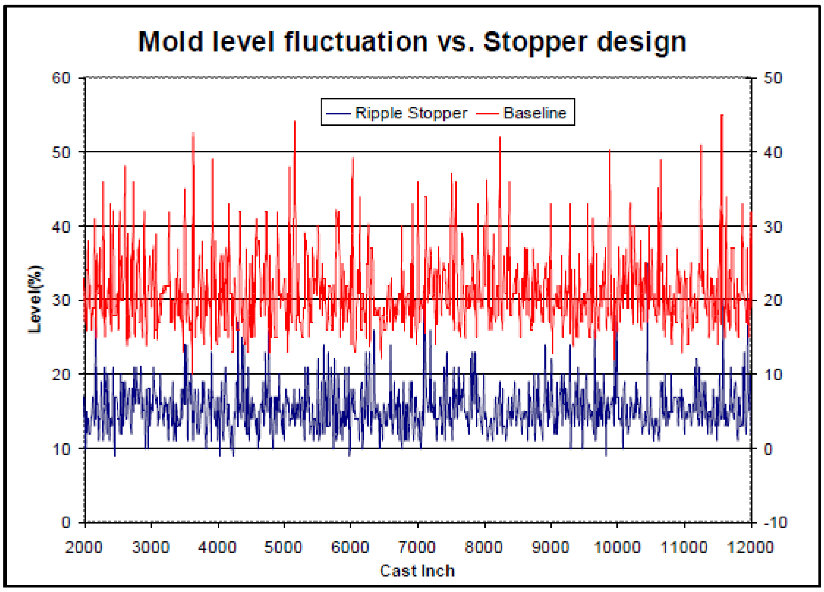


Figure 11. The level fluctuation comparison from an actual field trial (3)

4. CONCLUSION

In ultra-low carbon grades where the strength to weight ratio of steel is high, the steel production can be improved for final quality improvements by various means. Some of the areas covered in the topics, have substantial field trial results to back up finding from the theoretical and mathematical studies. Usage of these technologies by steel makers has helped them achieve their goals. The process improvement initiatives will lead to quality improvements and lead to increase in yield and productivity.

ACKNOWLEDGEMENT

Special thanks to Vesuvius Global Flow Simulation team and special thanks to Richaud J, Vesuvius France.

REFERENCES

1) Sengupta J., Shin H J., Thomas B.G., Kim S.H., Micrograph evidence of meniscus solidification and subsurface microstructure evolution in continuous cast Ultra- low carbon steels, Acta Materialia, Vol.54, No.4, February 2006, pp 1165-1173

2) Sengupta J., Thomas B.G., Effect of a sudden hook formation during continuous casting of ultra-low carbon slabs, Modelling of casting, Welding and Advanced Solidification processes- XI, TMS, 2006, pp 727-736

3) Richaud J., Chung J., Rogler J., Tundish Flow regulation with advanced refractory designs, METEC 2011, Fluid Flow and Multiphysics modelling session 17, pp 1-10

Innovations in Roll Cooling for Control of Flatness at Primary Cold Reduction

Santosh Chacko, Suresh Vasani & AK Ray
Lechler (India) Pvt. Ltd., Thane, India
Email: akray1952@gmail.com

In rolling process the most significant aspect is the generation of heat through friction and deformation in the roll bite and in a typical Cold Tandem Mill, work roll temperatures normally fall in the range of 55℃-70℃ with strip recoil temperatures and inter-stand strip temperature rarely exceeding 160℃ depending on product. Roll bite temperatures in slower heavily drafted stands can rise upto 300℃, diminishing with the reducing thickness and increasing speed in the downstream mill stands. In general the temperature parameters are dependent on drafting, steel grade, gauge and width.

The most important aspects are maintaining uniform, stable roll temperatures, circumferentially around the roll and transversely across the roll with optimum thermal crowns and minimum temperature differential in the upper and lower work rolls by means of effective heat extraction.

Because of the current demands on mills to process much lighter exit gauges from increased incoming hot strip thickness, much larger reductions are necessary on individual mill stands, such high reductions at a nominal width result in a larger area of contact with corresponding higher rolling force, friction and heat generation. All these factors affect uniformity of flatness of the strip during rolling.

In the present paper, the latest innovations in roll cooling keeping in view of control of flatness at primary cold reduction have been described.

Keywords: Flatness Control, Shape Control, Selective Roll Cooling, SELECTROSPRAY®

INTRODUCTION

Correct application of coolant in a rolling mill is critical in achieving high quality strip in terms of uniform flatness and long roll life. The issue has become more important due to increasing customer demands for perfectly flat rolled strips and current demand for processing of increased thickness of hot strips for production of much lighter exit gauges in cold rolling mills. Optimal application of coolant requires an understanding of both efficient and balanced application of coolants as well as the spray nozzle technology. Spray nozzles are the tools to achieve these important tasks of roll cooling. Coolant should be applied to achieve the most efficient heat transfer between the rolls and coolant. Temperature control between top and bottom rolls must be achieved to accomplish effective cooling of the rolls.

Irregular and asymmetrical rolling loads across the work roll cause a non uniform transverse temperature distribution. Hot zones on the roll lead to an increase in the roll diameter in those particular areas, changing the transverse profile and crowning of roll barrel. When the heat affected roll profile is transferred to the material, the profile and flatness in the strip is immediately degraded.

Selective roll cooling is an effective tool for maintaining uniform transverse temperature profile of work rolls. The SELECTROSPAY® system developed by Lechler controls flatness of the strip by adjusting the shape of the rolls. Normally installed on the final stand, it can control the strip profile by managing heat build-up in barrel of the roll.

HEAT GENERATION AND EXCHANGE IN COLD ROLLING PROCESS

During cold rolling, there are two sources of heat:

- Frictional heat generated at the roll bite by strip/ work roll contact.
- Deformation heat generated by the deformation of grain structure and work hardening during cold rolling

The Area of Contact (roll and strip) between the hard work roll surface and the softer steel strip is where friction is created, deformation occurs and heat is generated.

The "Area of contact" is defined by the strip width in the transverse plane and the circumferential "Arc of Contact" (AoC) between the roll and the strip (Fig 1).

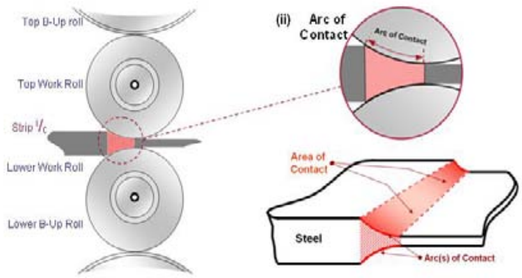


Fig 1 Area of contact during rolling

The area of contact varies with the changing AoC and the strip width thus a small reduction gives a short arc of contact and combined with narrow strip width gives a smaller area of contact and vice versa. The heat generated at the frictional interface (Area of Contact) and through the energy used in deformation is transferred into both the strip and the roll in roll bite.

In the rolling process where the area mass ratio is higher because the gauge is "thin", a large proportion of the "strip heat" is lost to air and coolant wash-over. However, heat absorbed by the rotating roll is subject to a more complex thermal mechanism. Heat will continually migrate to cooler zones in and out of the roll body due to the localized elevated temperature in the area of contact (bite) and localized "chill zones" created in the impingement areas of coolant sprays on the surface. The localized heat input/ output process results in a non-uniform distribution of heat, circumferentially around the roll and transversely across the roll body (Fig. 2).

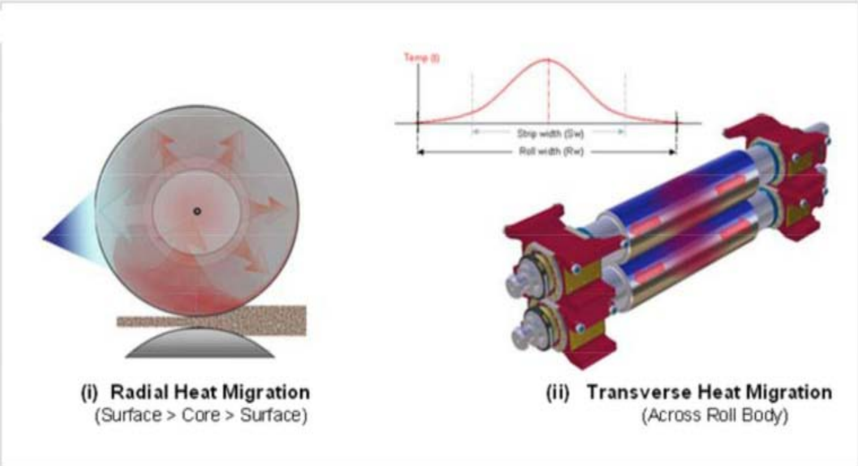


Fig 2 Heat migration in Cold Mill Work rolls (Hotter region shown in red)

Additionally, the roll is subjected to Thermal and Mechanical fatigue during rolling. High reduction schedules combined with requirement to produce a widening range of material cross-sections and a more varied range of softer and harder materials, results in increasingly greater challenges in control of roll temperature and the effective transfer of heat.

BASIC PRINCIPLES FOR CONTROL OF PROCESS HEAT

To establish heat balance it is imperative that heat transferred into the roll is transferred out. However, as the heat input and output is not distributed uniformly, the fundamental requirement to achieve effective heat extraction is to ensure

- The roll surface temperature range around the circumference is minimized for reduction of thermal fatigue and roll surface degradation as well as lowering the potential for surface defects, impaired lubricant performance and roll wear
- The transverse temperature distribution is controlled to assure strip flatness is not affected by excessive thermal crowning or excessive localized expansion across the rolling width and in particular at the edges.

It is also necessary to establish the same “temperature profile” on both top and bottom rolls as a pair to avoid differential thermal crowns and transverse profile.

Effective roll cooling is dependent on two major design objectives:

- Appropriate header geometry
- Optimum Footprint geometry of the spray

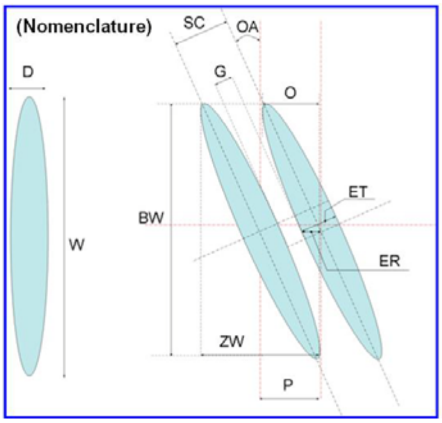
Ideal positioning of cooling headers (Fig 3) for most efficient cooling is rarely achievable due to several other conditions related to mill furniture layout, space availability, lubrication application etc. Therefore, it is necessary to apply fundamental principles in the design which assure the most effective layout within the space constraints.

Entry lubrication is either applied directly (DA) by separate header for lubrication system or indirectly (IDA) in the coolant. When direct application (DA) is deployed entry coolant headers must not impair the entry rolling lubrication. With indirect application (IDA), header flows can be balanced or with slightly reduced flows on the entry side.

Fig 3 Ideal coolant spray positions

Coolant headers on the exit side should be as near to the exit bite as possible to efficiently control heat migration into the roll body. The coolant applied to the entry side effectively transfers away the heat migrating to the roll surface after the exit side cooling zone. Therefore, in practice the optimum balance of coolant distribution in each side of the stand is best modelled to take account of the available space in the mill and best header positions around the roll.

Effective and precise Footprint geometry (Fig 4) of the spray is the fundamental requirement to establish a homogeneous cooling application and is achieved by the configuration of a uniform cooling area on the work roll, formed by the impingement of an array of adjacent sprays, equally spaced and positioned to assure consistent cooling intensity and impact pressure of the spray, transversely across the cooling area.



Footprint Calculations		
Code	Description	Value
a	Spray Angle	60 deg
d	Spray Distance (Nozzle to Roll)	200 mm
W	Footprint Width	230.9 mm
D	Footprint Depth	30.8 mm
P	Pitch (Nozzles)	55 mm
O	Overlap per side	58% 135.1 mm
G	Gap Between Footprints	14.4 mm
OA	Vertical Offset Angle	35 deg
BW	Band Width (Cooling)	189.2 mm
ZW	Zone width (Vertical)	132.5 mm
ER	Ellipse radius	37.5 mm
SC	Spray Center Distance	45.1mm
ET	Ellipse Depth	30.7 mm

Fig 4 Typical Flat Fan type footprint configuration

The key footprint parameters which have to be maintained are:

- The Gap to ensure adjacent sprays will not collide and interfere with each other

- The Overlap to compensate for the increasing gaps between adjacent oval-shaped footprints and the lower spray intensity at the outer width of the footprint due to curvature of the roll surface
- The Offset angle which dictates the circumferential coverage and the area of cooling

To ensure that the actual footprint impingement is correct, it is essential that the header positions are precisely maintained in relation to the roll center datum and pass-line (X-Y co-ordinates) so that impingement angles and impact pressure of adjacent sprays are identical, assuring uniform spray intensity.

SALIENT FEATURES FOR SYSTEM DESIGN

The ideal system layout is rarely achieved as the design has to take into account of the mill space and mill furniture which rarely affords optimum position of system hardware. Various modelling concepts like Heat transfer model, Heat/ Energy balance model, Spray impingement model etc. are used to achieve optimum design taking all the parameters and constraints into consideration.

Differential spray intensity on the exit versus the entry side of the roll stack are "by design" but any difference in the top and bottom cooling application lead to differential thermal crown resulting in inconsistent cold working on the upper and lower surfaces of the strip and ultimately uneven rates of roll surface wear in the top and bottom roll.

It is now established that it is more effective to increase water flow on the exit side in comparison to entry on a mill stand, on all but final stand where it is normal to have no exit side coolant to avoid carry-over of coolant/ lubricant so the layout on the exit side may differ from the entry side, but in considering top and bottom application, there should be no measurable difference in coolant application.

Thermal symmetry between top and bottom rolls is heavily dependent on:

- The application of equal flows to top and bottom rolls
- The geometrical and dimensional symmetry of the top and bottom header layout

All mills have different components above and below the pass-line due to which it is necessary to have customized solutions for cooling application.

SLECTIVE ROLL COOLING FOR CONTROL FLATNESS OF STRIP

Asymmetrical rolling loads across the work roll cause a non uniform transverse temperature distribution in the roll. Hot zones on the roll lead to an increase in roll diameter in the region resulting in change of transverse profile and crowning of the roll barrel which subsequently affects uniformity of strip flatness. The thermal profile and crown is controlled by selective roll cooling such that the roll bending remains "in range".

Flatness of rolled strip is referred to as "shape". A primary cold reduced strip exhibits two flatness states:

- Flat – Exhibits no waves, buckles or pockets, line bow or cross bow.
- Non Flat – Exhibits waves, buckles or pockets, line bow or cross bow.

Common flatness defects of strips are shown in Fig 5.

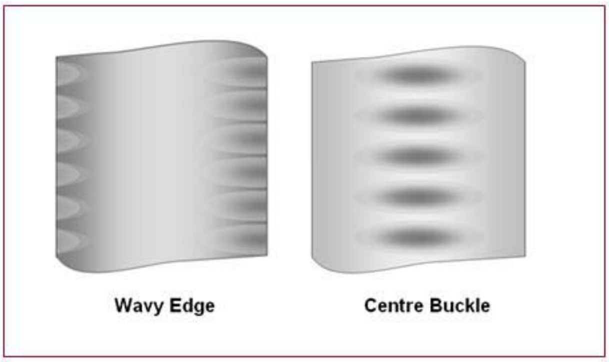


Fig 5 Common Flatness Defects in Strips

Over-rolling the center of the strip will result in center buckle and conversely over rolling the edges will result in waves at the edge of the strip. A localized thickness reduction on the strip produces a corresponding and proportional extension in strip length. Physically a wave or buckle running through a length of rolled strip results because the "unflat" section has been reduced more (thinner) and therefore elongated more and is constrained by the adjacent shorter sections. Under tension of the mill, the over-rolled (unflat) sections exhibit a lower stress, thus the shape-roll measurement principle actually records the comparative longitudinal stress value as a distribution across the strip width and display it as a deviation from the average stress.

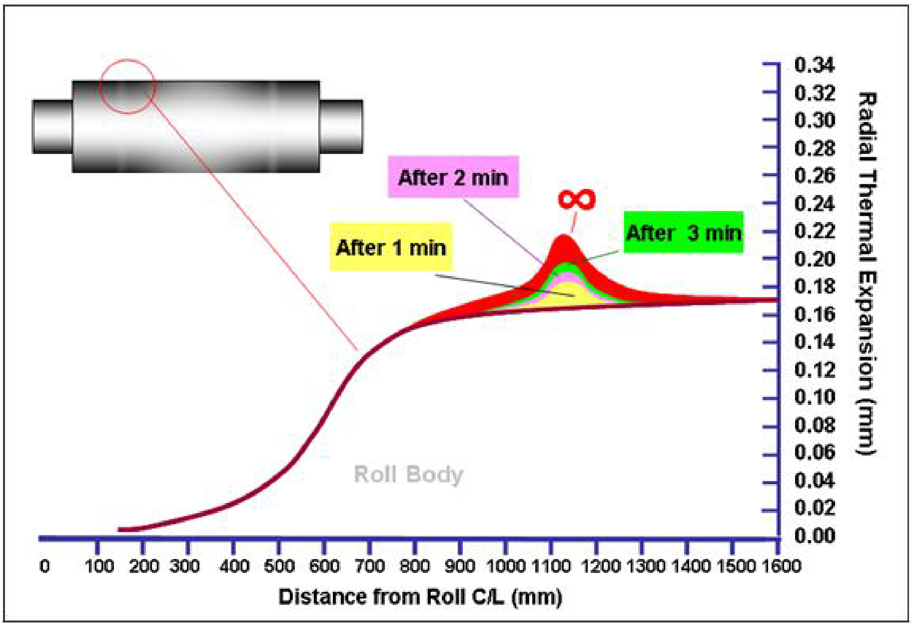


Fig 6 Transient temperature changes in roll

Fig 6 illustrates how "localized" transient changes in temperature across the roll body create "localized" expansion of the roll when a spray is turned down. The initial change is quite narrow and relatively fast on the roll but over the time it will grow in magnitude and area until a wave or buckle appears on the strip. Under such condition, the relevant Shape-roll sensor would register a lower stress value in strip corresponding to the affected (hotter) zone on the roll and initiate the coolant spray (Fig 7).

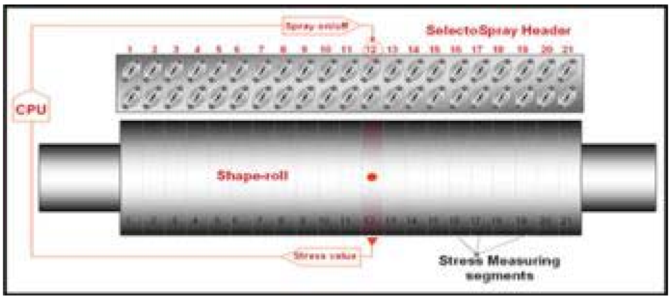


Fig. 7 Shape control system concept

The Shape-roll comprises of an array of circular segments or rotors each housing several radially mounted stress measuring sensors – typically a 26 mm or 52 mm pitch measuring the stress across the strip width as the strip (under tension) passes over the Shape-roll.

The Selective Roll Cooling system SELECTOSPRAY® (Fig. 8) developed by Lechler is used in conjunction with Shape-roll (stressometer), the configuration being dimensioned to exactly match the pitch of the Shape-roll sensors. For the purpose of control, the roll barrel is divided into zones which correspond to nozzle of the header. Each nozzle can trigger independently, controlled either by an operator or from an automated signal of stressometer. The electrical signal from the control activates a solenoid valve sending a pneumatic pulse to the header. These pulses turn individual sprays on and off as required using the MODULAX piston valve. With standard system configuration, there is no electrical connection to the header. When the nozzle in a given zone is shut off, heat builds up in that section of the roll resulting in an increase in diameter. If the nozzle is spraying, the opposite happens. By manipulating these hot and cold zones, the best roll profile can be generated at any given time and changed as necessary to maintain product flatness. The mechanism can even compensate to some extent for deformities in the roll itself.

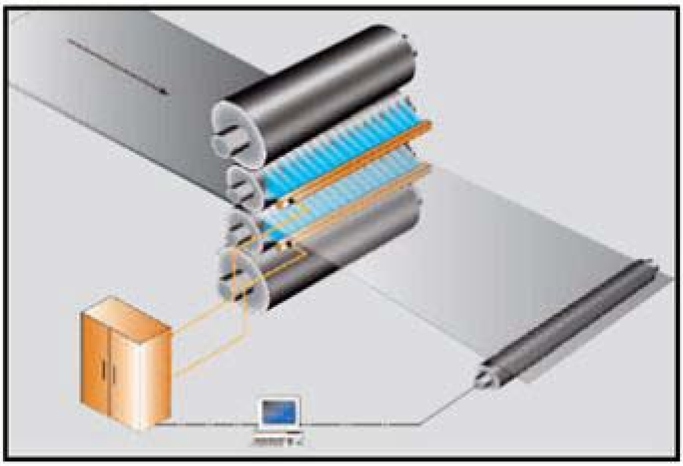


Fig 8 SELECTOSPRAY® system

The standard MODULAX valve is generally used to ensure effective operation in adverse mill conditions. There is only one moving part, a Delrin™ piston which seals the back of the nozzle mount to cut off or permit the flow of liquid. The piston is pressurized with air on one end and the coolant on the other. When the air pressure is released, the coolant opens the valve and allows the nozzle to spray. The piston area of the air end is larger, so the coolant pressure can be as much as two-times the air pressure and the valve will still function properly.

While the standard MODULAX valve is the first choice in most installations, there are alternate designs for specialty applications. These offer electric, electro-pneumatic control depending on the desired operating protocol.

Since the SELECTOSPRAY® is not the only selective cooling system found in mills, there are installations in the field that use designs by other suppliers. Often a given unit does not function as reliably as SELECTOSPRAY®, but due to cost constraints, it may not be possible to replace the system. Lecher offers a compromise which will allow to up-grade an existing installation without replacing all the hardware. The conversion valves using proven MODULAX technology offered by Lechler can be inserted directly into existing headers. These assemblies are direct functional equivalents for the original equipment, but provide operational improvements and increased reliability. No modifications to the header or control equipment are necessary.

POTENTIAL SOURCES FOR SHAPE DEFECTS AND REMEDIAL MEASURES

Optimizing the cooling system

A highly significant controllable parameter affecting the process for any given Tandem mill is the condition and effectiveness of coolant and lubrication system throughout the mill. There are two distinct subsystems for roll cooling in tandem mill:

- The back mill system comprising of simple single chamber or three or even five chamber headers in early stands
- The selective closed loop system on the entry side of the final stand comprising of stress measurement device and selective roll cooling.

For Shape Control System to produce best shape, back mill header performance is as important as the final stand. Therefore, the coolant application and hardware need to be monitored and maintained and standard operating practices must be followed in all stands, not just on those fitted with a sophisticated selective cooling application.

Strip and Roll temperature gradients

Any gradient in transverse temperature across the strip will change the shape as finished coil cools after recoiling (Fig. 9). Apart from most modern and demanding installations, transverse strip and roll temperature distributions are not universally monitored as a norm through the mill. Therefore, whilst a shape defect is physically corrected at the mill and the Shape-roll registers a symmetrical stress distribution and acceptably flat product for re-coiling, an undetected temperature gradient will cause the flatness to deteriorate as the coil cools. To avoid creating temperature gradients, it is necessary to assure that the coolant is applied symmetrically and rolls are cooled symmetrically.

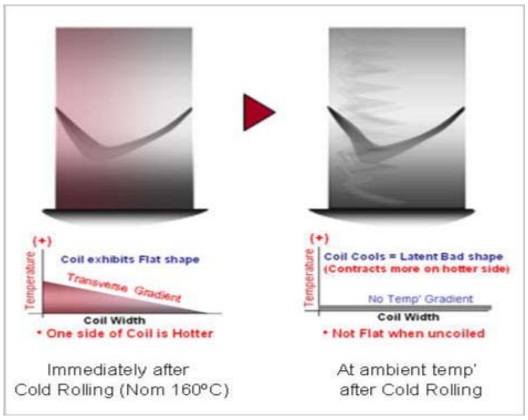


Fig 9 Transverse temperature gradient in strip

Major operational impediments to the system

- Uncontrolled dislocations of headers due to both mill events (such as wrecks, strip breaks etc.) and uncontrolled positional changes (Hardware modification) throughout the mill, particularly the heavily drafted stands (back mills) which are normally given little attention
- Deterioration of system hardware (nozzles, header condition, pump, filters)
- Poor coolant condition and consequential system contamination

Apart from the contribution to strip and roll temperature gradients through non-uniform spray cooling across the roll associated with detritus build up in a header, the most common fault is related to bad header position. Therefore, practical need is to ensure that the headers are set up parallel to the rolls whilst also delivering uniform flow and spray impingement over the roll barrel.

CONCLUSION

Roll cooling systems are designed to extract heat from the rolling process in a controlled and efficient way that assures optimum control of roll temperature, transverse thermal profile of the rolls, strip shape whilst minimizing roll wear and degradation without use of excessive volume of coolant. A well designed cooling system should achieve several important objectives:

- Maximum heat extraction with minimum application of coolant
- Symmetrical thermal profiles on the work rolls
- Controlled thermal crowns
- “Normal” steady state roll temperatures
- No differentials in the thermal conditions between the top and bottom work roll
- Ensure that the roll bending system is kept within range by maintaining the appropriate thermal crown height and symmetry

Selective roll cooling system is a useful tool for shape control of cold roll strips. The SELECTOSPRAY® differential roll cooling system developed by Lechler controls strip flatness by precisely correcting roll deformities. When combined with stressometer or other shape measurement device, the system can become closed loop, adjusting itself on the fly during the rolling process.

Strategies for Improved Wettability of Steels during Hot Dip Galvanizing

SK Mohapatra
R&D Centre for Iron and Steel, SAIL, Ranchi, Jharkhand-834002, India
Email: skm@sail-rdcis.com

With increased application of advanced high strength steels in auto sector, some challenges have come up in its processing in hot dip galvanizing lines necessitating suitable strategies to be adopted. Higher levels of Si, Al, Mn and Cr in steel lead to inferior strip wettability in zinc bath and coating defects. Surface oxide layers of 20 to 60 nm thickness, caused during annealing, impair wettability. In spite of protective gas atmosphere, oxide combinations of elements having higher oxygen affinity are created on strip surface, which do not get reduced in RTF contrary to iron oxides. Elements like Si lead to external oxidation, whereas Al leads to internal oxidation. Beside chemical composition, annealing parameters like dew point, gas composition and temperature also influence the selective oxidation process. The limits of Al in TRIP steel, Mn and Cr in other grades are discussed. Further, the influence of higher dew point in changing the nature of oxidation in DP and TRIP steels is illustrated. The oxidation kinetics in DFF and reduction mechanism in RTF at varying conditions are discussed for IF and Mn-Si-P steel. Influence of surface pre-oxidation on improving the zinc wetting and reactivity during hot dip galvanizing has been indicated.

Keywords: Galvanizing, Wetting, Selective Oxidation

Slab Quality and Mould Wear in Continuous Casting

Christopher G. Dilnot[1], Gerhard Hugenschütt[2], Dirk Rode[2], Hans-Günter Wobker[2] & Prashant Sahasrabudhe[3]
[1]Copper Technology Ltd., England
[2]KM Europa Metal AG & Co. KG, Germany
[3]Advanced Mould Technology India Pvt. Ltd., Bangalore-560048, India
Email: prashant@advancedmouldtech.com

The continuing cost pressure, as well as the desire, to further optimize product quality, pushes the steel producers to continuously enhance their production systems. In this sense the moulds on a continuous casting machine and their performance are of particular importance. The mould design strongly influences the performance and operating lifetime of the mould and as a consequence the achievable casting speed, the availability of the casting line and, in the end the productivity of the casting machine are all influenced. In parallel the mould design strongly influences the quality of the cast products which is of prime importance.

Within this article the influence of mould materials and coatings as well as cooling conditions will be identified, and the cause for typical failures / breakdowns characterized.

The two copper alloys copper silver (CuAg), and copper chrome zirconium (CuCrZr) are two mould materials which cover a wide area of application for mould broad faces.

In addition, in particular for mould narrow faces, nickel and/or beryllium alloyed materials are used, which offer superior hardness which in case of abrasive loads leads to considerably favourable wear behaviour.

When selecting the materials and coatings the wear of the "edges" of the narrow face has to be taken into account as this area can suffer heavy wear due to the size adjustments, which can lead to failures and even breakdowns in the casting process.

Keywords: CC Technology, Slab Quality, Mould Design, Mould Copper Alloys, Coatings, Wear

INTRODUCTION

Due to the worldwide pressure for steel production all steel works face the challenge of increased quality of the cast products, higher production rates due to faster casting speeds, and enhanced lifetime of the moulds. To reach these targets there is a mutual interest between steel plant customers all over the world with mould producers like KM Europa Metal AG GmbH & Co KG. No other component in the production flow influences the slab quality that much than the mould. These underline the importance of the continuous mould and especially the copper mould liner, which is in direct contact to the casting steel melt.

KME has a long history in continuous casting technology, and KME was involved from the very start of this new technology in the production of copper mould plates and copper mould tubes. Over all these years there is a close alliance between the steel plant customers, well-known machine builders and KME.

In order to achieve required results it is vitally important that steel plant companies, machine builders and sub suppliers work together to solve the problems. Today it's not enough to be just a sub-supplier to the steel plants, but you must be an innovation partner, who is offering its own engineering and consulting capability in all continuous casting process related questions. You must be able to offer solutions for new requirements with a flexible and innovative solution using the technology of optimised copper alloys and coating technology.

OPTIMIZATION POTENTIAL ON COPPER MOULDS

The mould performance is commonly represented by "number of heats cast" on a mould between refurbishment, replacement, exchange or repair, commonly called campaigns. The copper mould cost in relation to one tonne of cast steel is a more reliable statement. On average the cost of copper mould plates represents less then 0.2 % of the total slabs production costs. But it is important to consider the indirect costs linked to copper mould due to the related product quality.

In order to optimize the mould performance it is necessary to study the actual design and observe the reasons for refurbishment and slab failures. Based on the results of this analysis it is possible to improve the copper mould design by tuning the individual mould design to the individual requirements for optimum performance.

An optimal cooling design is the foundation for a good mould performance. This starts with a cooling water system that is designed correctly with the required capacity for water cooling, treatment, and filtration designed to the needs of the casting machine. Please take in consideration the smallest cross section in the closed water loop system which is the channels in the copper mould plates themselves. World wide experience has shown us that a very common problem is localised blockage of the water channels by dirt, rust, or other impurities. This creates local hot spots, which leads to localised overheating which can lead to cracks in the copper.

This point is especially relevant today with the higher casting speeds and the production of crack sensitive steel grades which leads to higher heat loads in the mould on the modern CC-machines, cooling issues are more and more important.

MOULD MATERIALS

The demands to be met by the mould liner material are related directly to the function of the liner and to the stresses involved. A relatively high strength and hardness are required, to fulfil the needs of handling, including assembly/disassembly. This is especially relevant for thin walled mould plates as used in thin slab casting lines.

The key job of every mould is the controlled cooling of the steel melt. The heat produced from the solidification process and the superheat of the steel must be conducted through the mould liner to the cooling water. This applies to all types of moulds alike and this necessitates a mould liner material with the maximum possible thermal conductivity.

During the casting process there is a considerable rise in mould liner wall temperature even with copper based alloys with there associated high thermal conductivity. Depending on the rate of cooling water (quality, velocity and flow rate), wall thickness of the copper plate and on the casting parameters (speed, mould lubricants, steel chemistry), the temperatures at the meniscus area may reach 200 - 450°C on the hot face and 100 - 200°C on the cold face. To give a comparison the corresponding temperatures on the hot face at the mould exit are in the range from 120 - 200°C.

Another property that is essential for the mould liners is a recrystallization temperature high enough to prevent or minimize softening of the metal, the critical zones for this is the high heat area around the mould meniscus area and the mould area adjacent to the steel stream as it enters the mould.

A mould plate with the corresponding thermal loads generates high levels of stress over a long period of time, as a consequence a material with high creep resistance is essential for stable operation of the mould liner. With continuous service such stresses result in creep and progressive distortion of the mould liner, this can only be minimised by materials which demonstrate high levels of creep resistance at the relevant operating temperatures.

Cracking due to fatigue loads resulting from varying temperatures at the meniscus area and special tasks in the casting system such as electromagnetic stirring systems are other aspects for the mould material, see Fig 1.

Mould function, type of exposure	Properties required
Handling; assembly/ disassembly	High thermal conductivity
Transfer of superheat and heat of solidification	High thermal conductivity
High wall temperatures	Retention of high strength at the relevant operating temperatures
Mechanical stresses at high temperatures	High resistance to creep
Heavily fluctuating thermal stresses (fluctuating meniscus level)	High resistance to fatigue and cracking
Strand/mould friction	High hardness and resistance to wear
Screening in electromagnetic stirring systems	Reduced electrical conductivity

Fig 1 Copper Material Performance Requirements[1, 2]

KME offers a range of copper alloys with a different range of properties which have been specifically tailored to meet the demands of continuous casting moulds; Copper silver alloy with its very high thermal conductivity, and a range of ELBRODUR® alloys based on CuCrZr and CuNiBe alloys are offered, see Fig 2. The ELBRODUR® alloys are age hardened alloys which offer unique combinations of thermal conductivity and strength/hardness at higher temperatures. ELBRODUR® G, GP and NIB are advanced mould materials (AMM®), which give their strength even at high temperatures. These alloys provide a base for excellent stability and constant geometry of the mould which together with modern mould coatings provides reduced wear and improved lifetime.

Material	Cu-GS	CuAg-GS/NS	ELBRODUR® G/GP	ELBRODUR® GR	ELBRODUR® NIB
Alloy system	CuAg	CuAg	CuCrZr	CuCrZr	CuNiBe
Thermal conductivity	High	Very high	High	Medium	Medium
Softening / Recryst.-temp.	Medium	Medium	Very high	Very high	Very high
strength / hardness	Medium	Medium	High	High	Very high
Application	Mould tubes	WF / NF for • slab • thin slab • BB moulds • mould tubes	WF/NF s plates for • slab • thin slab • BB • bloom moulds • mould tubes	Tubes and plates for • billet and • bloom moulds with EMS systems	WF/NF plates for • slab moulds • thin slab moulds

Fig 2 Properties and applications of AMM® Advanced Mould Materials[1, 2] (WF/NF = Wide Face / Narrow Face)

MOULD COATINGS

In mid of 1960s Cr-coating of mould tubes was introduced, later in the 70's Ni and Ni + Cr plating of mould plates were introduced. Since the 1990s a wider range of Ni-alloys such as NiFe and NiCo have been used. Around 5 years ago ceramic mould coating by thermal spray processes were developed, in some cases dispersoid coatings like Ni with SiC played a smaller role.

The coatings have a range of thermal conductivities from 30 to 90 W/(m•K), and hardness levels from 220 to 1200 HV, as the hardness increases the thermal conductivity reduces, see Fig 3. Costs are determined by the process used and by the thickness of the coating itself.

Approx. 70 - 80 % of all mould plates in the world are coated, mainly with nickel or nickel alloys; in markets with the possibility of recoating during maintenance the percentage is even higher. The different coating options are well known: step coating 1 to 3 mm or up to 3 mm bottom half Ni coating is most popular.

KME Coating	Material	Coating system	Hardness	Thermal Conductivity	Thickness
			HV	W/(m•K)	mm
HN 20	Nickel	Electrolytical Deposited	220	90	< 7
HN 40	Nickel-Alloy	Electrolytical Deposited	400	80	< 3
HC 90	Chromium	Electrolytical Deposited	900	70	< 0.15
HF 120	Metal-Ceramic	Thermal Sprayed	1200	30	< 0,5

Fig 3 AMC®-Advanced Mould Coating

There are some advantages of Ni/Ni-alloy coatings like initial low cost, economical in regards to costs per cast tonnages, combinations with different coatings possible avoiding star cracks, reduction in heat flux for crack-sensitive steel grades and resistance to dummy bar damage and other operations failures.

SLAB QUALITY

The behavior and surface condition of the shell during the initial solidification process in continuous casting have an important influence on the final slab quality, Fig 4. Most of the quality problems, like cracks and surface defects, are believed to be initiated already in the meniscus area of the mould by thermal and mechanical stresses, and they propagate as the strand progresses through the caster and during downstream processing.

It is well known that peritectic steels, with a carbon content in the range of 0.08 - 0.14 %, are particularly vulnerable to cracking, this is because hot ductility is reduced in that carbon range, and these steel grades are the most difficult to produce with respect to the surface quality.

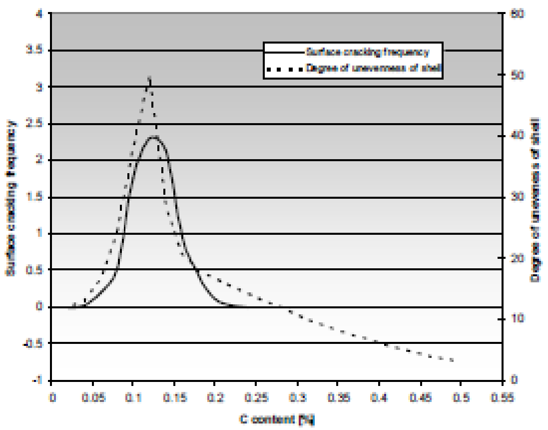


Fig 4 Influence of carbon content[3]

Most common surface cracks on cast slabs, which develop during the casting process and limit the further processing of the slab, are longitudinal and transverse facial cracks as well as longitudinal corner cracks. The frequency of these facial cracks reaches its maximum above mentioned with carbon contents in that range. The dependence on the carbon content is due to the changes in microstructure during solidification.

Furthermore it has been noted that the solidifying shell grows unevenly because of the peritectic change. This uneven shell growth leads to weak regions or dangerous "hot spots", i.e. shell areas thinner and hotter than the surrounding region, with low mechanical resistance.

Also other steel grades are affected significantly by the initial solidification phase together with transformation. In these steels such as low carbon, hyperperitectic and silicon-alloyed grades, defects may occur in the form of "surface irregularities".

But even for these grades advanced techniques are available that allow the steel mill to produce them. However certain defects show a presence that is random and difficult to relate to processing conditions.[4, 5]

DESIGN INFLUENCES ON COPPER PERFORMANCE

Whilst the mould material and coating are very important the mould design plays a very important part in the mould performance. To reach the target of a uniform heat transfer, especially in the meniscus area, it is essential to choose the right geometry of cooling channel arrangement. In the past the standard slab mould design was based on symmetrical, uniform cooling design. From the thermocouple measurements it is well known that the heat load on the mould wall is not equal. In order to guarantee a uniform temperature on the hot face, it is necessary to take into account the variable heat-load by the use of a modified cooling design to accommodate this variance. This often requires a specialised design with a range of slot widths with different distances to the hot face in combination with drilled cooling passages. An excellent example of this is the influence on the thermal load of the fastening studs and the measures required to minimise this effect.

In order to minimise the material stresses in the copper mould plate special solutions are necessary. On most standard mould designs they do not allow the copper material to move. However the copper mould plate needs the freedom for thermal expansion during casting to avoid plastic deformation followed by material creep at the end of the casting process. It is this extreme change in temperature at the beginning or at the end of the casting process which gives the maximum stress levels.

A very good example of this typical plastic deformation can be seen on a thin slab copper mould plate in CuAg. Here you can see strong “bulging” effect in the meniscus level after the first heats. This is related to an extreme local heat load in combination with the inner tensions prevalent in cold forged copper mould plates which can result in a plastic deformation (creeping effect).

To optimize cooling conditions you must take into account fluid dynamics as well as the internal stresses present in all mould plates. KME’s unique “Three Dimensional Finite-Element-Analysis Models” (FEA) are the-state-of-the art techniques which allow to study different effects and provide an optimum solution. KME whilst known for its manufacturing of copper mould plates can also offer a unique consulting service to the steel industry to optimize casting conditions as well as engineering services including FEA calculations. Fig 5 shows a typical example of an improvement to the cooling design on a slab mould showing the resultant homogenous temperature distribution.

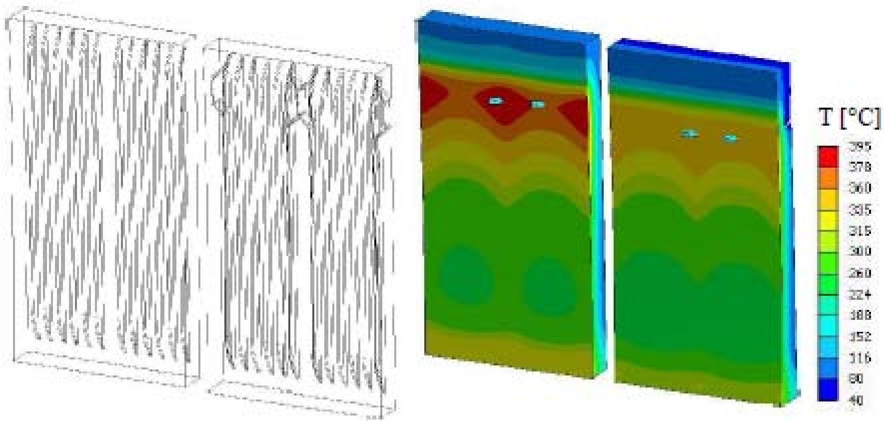


Fig 5 Mould cooling improvements

Whilst it is well known that the basis for an efficiency cooling is a constant water quality, it is not generally known that a thin calcium layer in the water passages has a dramatic influence for the heat transfer, it can be seen from the Fig 6 below the dramatic effect on the heat transfer and temperatures.

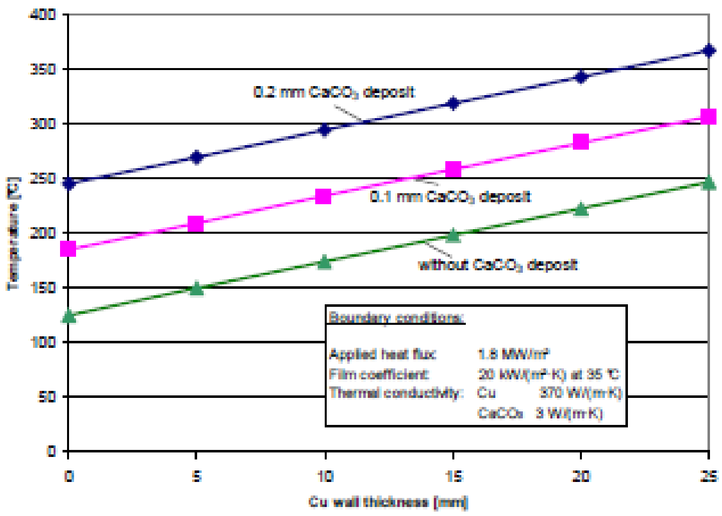


Fig 6 Temperature increase due to scale deposits[6]

It is generally recognised with modern CC machines that the water velocity needs to be designed above 8 – 10 m/s. To achieve this target older CC machines can be redesigned. One common solution is to reducing the water channel cross sectional area to achieve higher water velocities without increasing pump capacity. Another technique can be a change in the water flow direction to move the inlet water to the top of the mould allowing the colder cooling water into the hottest zone of the copper plate.

MOULD WEAR

"Bottom wear" on slab moulds can be related to different reasons. Beside the normal friction of the strand shell very often cavitations can observed, Fig 7. If there is incorrect adjustment of the spray nozzles or the wrong type of nozzle is fitted in the first spray zone between mould and first foot roll water is guided between strand shell and copper plate. This water immediately forms steam and explodes and taking small Cu and/or coating particles out of the mould plate surface. This effect can be dramatically increased with the presence of Flouride from the casting powder which results in formation of hydrofluoric acid, this acid is extremely corrosive and it can strip all coatings from the copper including ceramic coatings.

Handling damage, dummy bar insertion damage, poor packaging of the dummy head and of course the length of sequences are all factors which influence the "bottom wear".

Fig 7 Typical bottom wear at a slab mould, related to friction and cavitation effects

EXAMPLES OF MOULD DAMAGES

With the use of the afore mentioned anti-wear-coatings good results with respect to the life time of the mould plates and the reduction in the costs of the casting process could be achieved.

But we should also note that there are a lot of factors which can have a negative influence on the moulds which can dramatically influence the mould lifetime. Most critical damages are caused by a "high temperature effect" and/or with the influence of undesirable chemical elements. Examples of these elements are Zinc, Cadmium, Lead, Bismuth, and Tin, these elements originate from the scrap which is transferred into the steel melt. As mentioned previously Fluoride from the casting powder has been seen to have a major detrimental influence and this is a common defect seen worldwide.

In addition there is the risk of mechanically damaging the plate surfaces with adjusting procedures. The pictures shown are good examples of what is typically seen and these can give you an imagination of the potential damaging effect.

A common problem is when hard particles are caught between the narrow and the broad face plates during size adjustment and is shown in Fig 8.

Fig 8 Narrow face plate with damaged edge at the corner by hard particle[7]

Here we can see a deep impression, which deforms the copper material, the Ni-coating itself reacts without a problem, but due to the deformed copper contact surface a localised high wear is caused.

Another interesting example shows the influence of more than one negative factors at the same time. An ELBRODUR® plate was damaged by a strong crack network in the Ni-coated acting meniscus level (Fig 9).

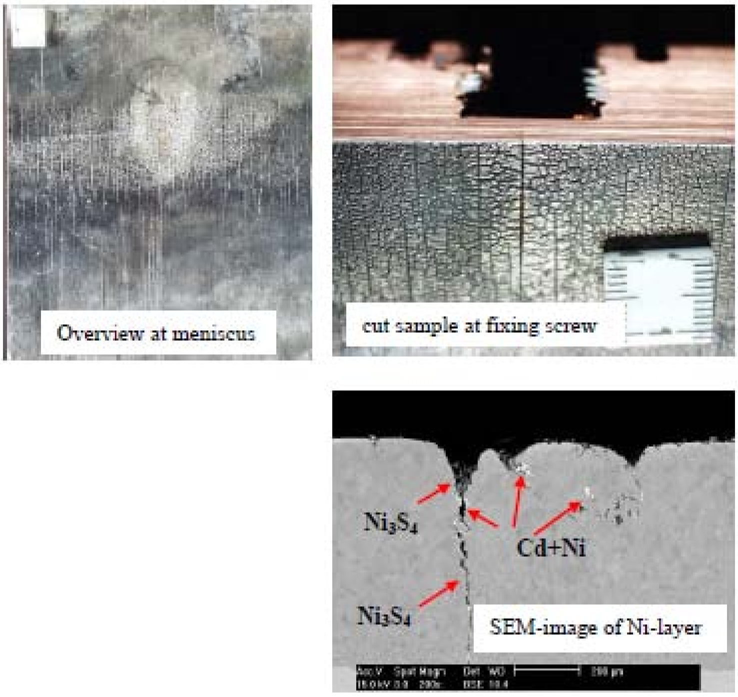


Fig 9 Meniscus area with damaged Ni-coating due to overheating and Sulfur-/Cadmium-embrittlement[8]

The laboratory examination of the failed copper plate showed the mould plate had been exposed to very high temperatures even for the ELBRODUR® G material with its high strength at higher temperatures. This high temperature effect had softened the copper from 220 to 100 HV. The cause of this was an “operating meniscus level” in the mould above the “design meniscus level”. The design of the mould plates did not allow for the cooling at the higher level and this resulted in consistent high temperatures of approx. 350 - 400°C. This directly resulted in the cracking of the Ni-coating; in addition Sulphur and Cadmium acted as embrittling phases in the nickel-matrix and intensified the damaging effect. The recommendation of the investigation was to operate the meniscus level at the correct depth with the required cooling, and the main problem was solved. However it is worth noting that this is a good example which by use of FEA modelling it may be possible to alter the design to improve the cooling in the upper levels.

The reduction of the rogue element effect of Cadmium in the steel melt - when possible – should give further improvement and safety against cracking. It is recognised that this is not always possible, but this effect can be minimised by the reduction of mould plate temperatures.

OPTIMIZATION POTENTIAL ON COPPER MOULDS

All steel plants want to maximise or stretch the lifetime of the moulds and increase the casting speeds, this is especially important in the development of the thin slab production process. However these two factors are incompatible on thin slab moulds as the increase in casting speeds results in a dramatic reduction in mould life and it has a limiting effect on casting speeds with conventional designed moulds, Fig 10.

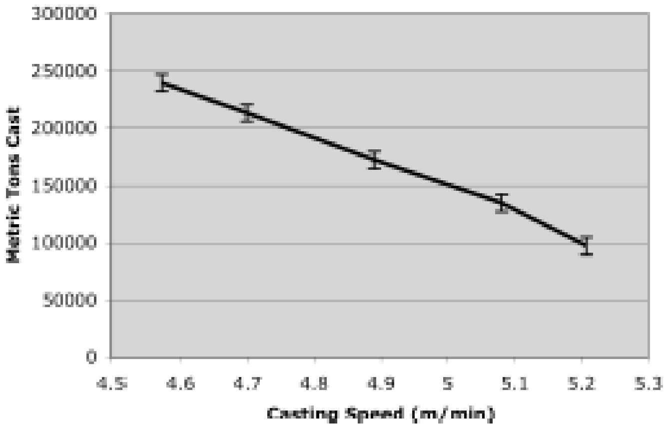


Fig 10 CSP Mould life vs. casting speed[9]

KME's new enhanced thin slab casting "Advanced Funnel Mould" (AFM) has been designed to meet both objectives. The design has been made to allow the mould plate freedom to move, this reduces the internal stress levels and in combination with improved copper alloy properties, optimized coatings, and surface texturing this new development is designed to meet the demands of the next generation of thin slab casting machines like the new ARVEDI ESP Caster.

But this development can not only be by the mould, it also needs further developments on the casting powder, the submerged entry nozzles and the EmBr's. Today's copper alloys can't withstand the high heat flux for thin slab high speed casting, especially in the meniscus area for a longer time. Therefore it's necessary to reduce the local heat flux peak and spread it over an increased region.

CONCLUSION AND OUTLOOK

There is a continuous requirement on steel producers to optimize the production process in terms of productivity, stability and product quality. In this sense the moulds and their performance are of particular importance of the overall productivity of the casting line.

With the available AMT®-technological packages it is possible deal with most of the problems that may arise on moulds and their auxiliary systems. The available FEM technology allows to simulate mould performance and thermal and mechanical loadings. Furthermore this approach can be used to better understand the influence design changes avoiding hot tests in moulds.

Based on modern mould materials, i.e. CuAg and ELBRODUR®G, tailor made materials for individual applications are available. Modern mould coatings have proven to be very effective in reducing mould wear.

For an efficient improvement of moulds and casting liners the interaction of the mentioned parameters has to be understood. KME offers these combinations of products and experience for the production of high performance moulds and serves as a partner for steel plants to optimize continuous casting processes.

REFERENCES

1) KME Germany AG & Co. KG, Prospect Special Products, AMT – Advanced mould technology, (2004), p.21

2) D. Rode, KME Germany AG & Co. KG, Prospect Special Products, Copper and copper alloys, moulds for continuous casting of steel, Technical Information No. 0895, (1995)

3) E. Kivelä; Improvement of the surface quality of slabs by mould heat transfer optimization when casting crack-sensitive grades; ATS Steelmaking Days, (1992)

4) A.S. Normanton; V. Ludlow; A.W. Smith; A. Gotti; M. Thiemann; S. Landa; J. Wans; Improving surface quality of continuously cast semis by an understanding of shell development and growth, (2003)

5) P. Müller, H.-G. Wobker, D. Kolbeck, G. Hugenschütt, H.-D. Piwowar, L. Schmitz, “Technologies for casting crack-prone steel grades”, METEC- Conference, Düsseldorf, (2007)

6) H.-G. Wobker, G. Hugenschütt, D. Kolbeck, “Use of FEM Simulation to optimize continuous casting moulds”, AISI Conference, USA, (2001)

7) H. Schulze, KME Germany AG & Co. KG, Internal report, (2008)

8) H.J. Hemschemeier, KME Germany AG & Co. KG, Internal report, (2002)

9) I. BAKSHI, KME America Inc., Continuous Casting Course, AIST 2007