

EUROPEAN STEEL TECHNOLOGY AND APPLICATION DAYS 2017 - ESTAD 2017

Monday 26 June 2017 - Thursday 29 June 2017



Book of Abstracts

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Blast Furnace Ironmaking / 3**Mathematical model to simulate liquid metal & slag accumulation, drainage and heat transfer in blast furnace hearth****Author(s):** Mr. UPADHYAY, Hemant¹**Co-author(s):** Dr. KUNDU, Tarun Kumar ²¹ *Jindal Steel & Power Ltd, Raigarh, India*² *Department of Metallurgical and Materials Engg. Indian Institute of Technology, Kharagpur, India***Corresponding Author(s):** hemant_upd@jspl.com**Abstract**

Proper understanding and control of accumulation, drainage and heat transfer of hot metal and slag in BF hearth is essential for a stable and efficient blast furnace operation. Abnormal drainage behavior may lead to high liquid build up in the hearth. Operation problems normally be encountered if the liquid levels in the hearth exceed a critical limit when hearth coke and deadman start to float. This not only cause sluggish or irregular descent of burden material but also result in irregular casting intervals, damage to lining, low blast intake and furnace pressurization. Similarly hot metal temperature is an important parameter to be controlled in the BF operation; it should be kept at an optimal level to obtain desired product quality and a stable BF performance. To predict the hot metal temperature variation during tapping process is extremely useful since it gives a clear picture to operator about the tapping operation and prevents any panic. At the same time it allows the correction of process parameters in case of any major deviation. The hot metal composition and quality depend on the casting temperature of the hot metal. If it is too high or too low it may directly affect the process and cost efficiency of BF as well as BOF plants. The level & temperature of the liquids in the hearth varies with time and is not fixed, it greatly changes with the tapping durations and production / drain rates along with changes in blowing parameters and fuel supply. Efforts have continuously been made for BF process optimization to improve its productivity, energy efficiency, environment and product quality. The control of the hot metal / slag accumulation, drainage pattern & tapping temperature is of great importance in order to optimize the BF process and make it productive, energy efficient and cost competent. Therefore it is utmost important for a furnace operators to understand the mechanisms governing the liquid flow, accumulation, drainage and heat transfer between various phases in blast furnace hearth. It is very difficult to carry out any direct measurement due to the hostile conditions in the hearth with chemically aggressive hot liquids. Hence estimation and simulation based on rules of physics and mathematical calculations, taking in account available operating parameters, is only viable solution.

The objective here is to develop a mathematical model to simulate the variation in hot metal / slag accumulation and temperature during the tapping of the furnace based on the computed drainage rate, production rate, mass balance, heat transfer between metal and slag, metal and solids, slag and solids as well as among the various zones of metal and slag itself. The developed model is able to predict & give real time picture of state of liquids in the hearth, which is in good agreement with the actual plant data.

New Ironmaking Technologies / 5**Yield improvement at direct reduction plant, module-E by modifying oxide screen-mesh****Author(s):** Mr. SAMMAN, Mohammed¹**Co-author(s):** Mr. HANAFY, Hesham ¹ ; Mr. AL-OTAIBI, Theeban ² ; Mr. AL-JUTAILI, Abdulaziz ² ; Mr. AL-WENAI, Mohammed ²¹ *SABIC, Technology Management, Metals Business Unit*² *SABIC, HADEED***Corresponding Author(s):** sammanme@sabic.com

Module-E, one of the largest MIDREX direct reduction plant in the world with more than 2.5 MT iron oxide consumption. The oxides used in its Shaft Furnace (SF) is in pellet shape of

size 6 to 18 mm diameters. However, during palletization process at suppliers' locations, and transportation afterward, undersized pellets are generated. In the plant, undersized materials are screened off from feeding materials and sent to by-product hoppers prior the SF. Hence, having good screening system is crucial in minimizing oxides losses.

In previous study, it was estimated that more than 50% of 3-6mm fines in by-product hoppers contain larger than 6 mm oxide pellets and 85% is +5mm oxide pellets. These good materials can be utilized in the SF.

Recently, new oxide screens with new configuration were installed. The proper modification of the oxide screens at Module-E showed noticeable saving of more than 45,000 Tons/year as a prime iron oxide.

Keywords: *Iron pellets; Process optimization; Oxide screens*

Blast Furnace Ironmaking / 6

Blast furnace smelting of the titaniferous magnetite ores with the various content of titanium dioxide and quality of the agglomerated raw materials

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It is analysed some titaniferous magnetite deposits of Russia. The results of laboratory, industrial and calculation (by means of mathematical models) researches of physical, chemical and thermophysical processes at oxidizing roasting (agglomeration) of the titaniferous raw materials are considered. The rating of influence of metallurgical properties (reducibility, durability, softening and melting temperatures of agglomerated ores) on processes heat and mass exchange at the reduction in blast furnace is executed. Titan-bearing ores with the various TiO₂ content are investigated. It is shown that the main reserve of coke consumption decrease and improvement of the technical and economic indicators of blast furnace smelting is improvement of quality of iron ore raw materials.

Secondary Metallurgy / 10

In situ measurement of silicon content in molten ferrochrome

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Outokumpu Stainless Tornio Work is an integrated steel plant, which features production of molten ferrochrome at the same site. The refining of the molten ferrochrome is conducted in an ferrochrome converter, which is essentially a modified argon-oxygen decarburisation (AOD) converter. The process control of the ferrochrome converter is based on composition samples and temperature measurements. As the composition analysis takes several minutes, the process model has to determine the blowing scheme without accurate a priori knowledge of the composition of the metal bath. From the perspective of process control, the most important element at the initial stage of blowing is silicon, the content of which has a considerable effect on the energy balance. In the field of steelmaking, disposable emf sensors have several applications as fast and convenient measurement system, which supports conventional composition measurements. Nevertheless, the application of disposable emf sensors in ferrochrome refining has not been studied exhaustively.

The objective of this work was to study the application of emf sensors for the measurement of silicon content in refined ferrochrome melts. The employed measuring equipment included a Multi-Lab III central unit, Celox HM-Si probes and additional equipment manufactured by Heraeus Electro-Nite.

Because the emf signal is a measure of the oxygen activity, it is an indirect measure of the content of species with highest affinity. In order to determine whether silicon has the highest oxygen affinity, theoretical emf values were calculated for the selected elements (Si, C, Cr and Ti) in the molten ferrochrome. Based on the obtained results it was possible to discard part of the elements in further considerations. The sensitivity of the computational emf value of silicon with respect to temperature and composition was then studied in more detail. Preliminary results suggest that disposable emf sensors can be employed for measurement of the silicon content of ferrochrome in the studied period of refining.

Cokemaking / 11

New technique for coal size design based on unique thermoplasticity index

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It becomes more important to properly prepare raw coal blend for cokemaking since required coke quality has been increasing. In particular, because coal size adjustment is an important operation which strongly affects coke strength, various control technologies for coal size have been developed. General coal size design has been almost based on the well-known Sovaco method. In the method, firstly coal is classified into fine grain group including more active components with high caking property and coarse grain group comprising rich inert components whose caking property is poor. Secondly the inert components group is crushed by closed-circuit system so that the size becomes smaller than the set screen mesh. The method suggested that coke strength is improved due to suppress formation of cracks in coke by intensively crushing and dispersing inert components. On the other hand, in our previous report, a new measurement method for unique coal thermoplasticity, "permeation distance method", was devised. As a feature of this method, the permeation phenomenon in which thermally plastic coal permeates into the surrounding voids, which is assumed to occur in actual coke ovens, is evaluated under the circumstances experimentally simulating coke oven environment. It was clarified that coal having longer maximum permeation distance forms larger pore and thinner pore-wall structure in coke and that coke strength deteriorated when the coal blend included longer maximum permeation distance coals. In this study, we investigated an influence of coal grain size on permeation distance and coke strength. If permeation distance can be changed by coal size, adverse effect of longer maximum permeation distance coals on coke strength would be reduced. Through the experimental results, effective formulation about optimum grain size of coal blend was explored from a perspective of control of permeation distance.

Applications & Galvanizing / 12

Galvanizing of 3rd generation AHSS-grades with PROBOX®-technology and flexible thermal treatment

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3rd generation advanced high-strength steel (AHSS) grades are complex materials with special chemical compositions and multiphase microstructures. The annealing and galvanizing process of these grades is different and places new demands on the plant technology. One of them is the

prevention of surface faults. Bare spots can occur due to a higher content of alloying elements like silicon or manganese. Prevention is possible with the PrOBOX®-Technology for pre-oxidation. Another important topic is a precisely controlled and very flexible heating and cooling processes. The PrOBOX®-Technology is a proven solution for hot-dip galvanizing of high-alloyed steel grades without wettability problems, which normally occur during the conventional galvanizing process. The strip surface is therefore purposefully oxidized and reduced during the process. The technology is characterized by a very accurate formation of the iron oxide layer thickness, which is also measured. Another highlight is a specific technology which makes sure that the major part of the injected oxygen migrates into the strip surface. In addition, contamination of the furnace atmosphere by excessively discharged oxygen is prevented. Crucial for the production of modern grades is an appropriate furnace technology. The highly-efficient radiant-tube furnaces are equipped with powerful heating and cooling systems and facilities for quench and tempering. The newly developed I-Furnace optimizes the heat treatment and production process. It smartly combines a mathematical/physical model to control the furnace and to optimize production with an online strength measurement system and a newly developed annealing microstructure model to predict material properties after the heat treatment. This paper presents concepts for modern galvanizing lines for the production of 3rd generation advanced high-strength steel grades. It focusses on the pre-oxidation technology as well as on cooling technology and furnace control.

Rolled Properties and Characterizations / 13

Influences of the changed chemical composition of modern AHSS-grades on the pickling process

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The changed chemical composition of modern advanced high-strength steel (AHSS) grades has certain influences on the pickling process. Especially the higher contents of silicon and manganese have a critical impact on the process, which leads to problems in conventional pickling lines. The most significant challenges are sludge occurrence, varying pickling times, changed visual appearance, required high surface qualities, and weld ability. Based on the turbulence pickling technology SMS has developed some features and modifications, which allow an efficient production of these new materials. The higher sludge occurrence is based on the higher silicon content. Due to the huge experience with electrical steels with high silicon contents, appropriate solutions are available. Sludge removal is possible with the proven two tank system and a sedimentation system before regeneration. Furthermore, the high turbulence flow in the pickling section prevents sedimentations. The Eco-pickling and production model controls the process, which pickling parameters can be changed quickly to apply varying pickling times when necessary. In addition, the turbulence pickling system ensures a homogeneous surface quality and removes impurities from the surface. SMS offers the X-Pro® laser welder for a safe and reliable connection of the coils in the entry section, which is perfectly suitable to weld grades with high alloying/silicon contents. The integrated, patented inductive weld seam heat treatment for most difficult weldings is an essential feature of this machine. The automatic weld parameter calculation based on material cast analysis as well as the automatic measurement and adjustment of weld gap and weld position are supporting the production of these materials. Another highlight is the short cycle-time of less than 60 seconds. This paper describes the influences of the changed chemical composition of modern steel grades on the pickling process and gives an overview about the technical solutions.

Cokemaking / 14

Control technique of coke rate in shaft furnace by controlling coke reactivity

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The shaft furnace is a scrap melting furnace which produces high calorie gas and thus plays an important part as an energy supplier in a steel works. In shaft furnace operation, the coke rate is reduced or the exhaust gas calorie is increased corresponding to the energy balance in the steel works. Because the coke rate and exhaust gas calorie are determined by coke gasification reactivity, the reactivity control technique is very important. In this study, the coke surface was coated with CaCO₃, Fe₂O₃ or SiO₂ to control coke reactivity, and the gasification rates were measured at 1573-1773K. As results, the gasification rate was accelerated by CaCO₃ and Fe₂O₃ and decelerated by SiO₂. The acquired gasification rates were applied to a one-dimensional mathematical model of the shaft furnace. Shaft furnace operation with controlled coke reactivity was simulated, and the effects of coke reactivity on the coke rate and exhaust gas calorie were estimated.

Advanced Rolling / 15

Understanding scale defect in Si bearing automotive grades manufactured through the CSP route at Tata Steel, Jamshedpur

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Si bearing automotive steels manufactured from the Compact Strip Production (CSP) are used for making the surface critical Wheel & Rim application. A lot of scale issues are encountered in these grades making it very difficult to meet the urgent needs of the customer and it also leads to a lot of downgrading at Tata Steel's premises. A cross functional project was undertaken at Tata Steel's CSP to overcome this issue through a novel approach of fine tuning of the chemistry of the scale and process parameters optimization in the Finishing Mill of the CSP plant. Based on the successful outcome of these trials, the modified chemistry and the process parameters were incorporated in the Standard Operating Procedures. This paper showcases the journey which Tata Steel's CSP embarked upon w.r.t. study of the process parameters and the implementation of the key learning associated with it.

Oxygen Steelmaking / 16

BOF process improvements by modern gas purging strategy and technology

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BOF bottom gas purging has been established as inevitable technology for high quality demands at decreasing conversion cost levels. The trend for applying raw materials with higher variations in phosphorus at the same or increasing product quality levels increases the need for reliable, save and long-term available inert gas purging. Higher converter lifetime at decreasing converter refractory costs are however realized with increasingly intense slag maintenance methods. Technical solutions are needed to achieve both targets. Based on decades of experience in BOF gas purging at converters worldwide, RHI has developed recently both new purge plug designs and new gas control units to achieve maximum purging availability when converter slag maintenance is applied. The revised product portfolio covers purge plugs from standard to highest gas flow rates and modern and compact gas control in order to realize new concepts of gas purging for improved metallurgical results and gas savings at highest safety standards. Recent case studies are presented.

Blast Furnace Ironmaking / 18**New designed long-life copper stave cooling system for blast furnace****Author(s):** Mr. KIM, Jungil¹**Co-author(s):** Dr. MOON, Ki-Hyeon¹; Mr. NAM, Yong-Ho¹; Mr. CHO, Myung-Ho¹; Mr. KIM, Jan-Won²; Mr. CHOI, Sang-Woo¹¹ POSCO² Material Science and Engineering, Inha University**Corresponding Author(s):** jungil.kim@posco.com

Pohang No. 4 Blast furnace, inner volume 5600m³, was relined and blown in at 8th October 2010. The first failure in copper stave cooling channel was found on 20th. June 2014, 44months after blow-in, in belly. When the copper stave cooling channel in blast furnaces had been damaged in POSCO, cooling plates were installed from the outside of furnace shell to recover cooling function in the past. However, shell crack or hot spoats on the shell was repeated due to insufficient cooling power and refractory. It is decided to replace the old staves to new designed ones whose defects are supplemented, in order to minimize the harmful impact on furnace shell. The new designed copper staves installed from 2 Nov. 2015 in Pohang No. 4 BF to exchange the old ones which have had cooling channel failure. The front refractory brick in the new designed copper stave has been not damaged since it was installed, over 1 year. The new designed cu-stave is designed for distributing stress between refractory brick and stave as well as inter-refractories. It is expected that this innovatively designed cu-stave can prolong the service life of most of Cu-stave BF dramatically.

Electric Arc Furnace / 19**CFD modeling of standard and shaft-type Electric Arc Furnaces****Author(s):** Mr. ODENTHAL, Hans-Jürgen¹**Co-author(s):** Dr. KRAUSE, Fabian¹; Dr. VOGL, Norbert¹; Dr. KEMMINGER, Andreas²¹ SMS group GmbH² SMS-Group**Corresponding Author(s):** hans-juergen.odenthal@sms-group.com

In the Electric Arc Furnace (EAF) chemical and electrical energy is used for melting and superheating of scrap and DRI/HBI. Although the fluid-dynamic and thermodynamic phenomena during the different furnace steps are qualitatively known, some of these effects may cause process problems. To serve as an example, a free-burning electric arc not covered by foamy slag overheats the furnace walls (hot spots). Another example is the erosion of refractory lining due to high velocity and temperature gradients close to the wall. However, it is a challenge to implement such phenomena in an overall numerical model.

Nowadays, CFD (Computational Fluid Dynamics) is able to provide a detailed insight into the EAF process. SMS group has developed a holistic CFD EAF model (3d, multiphase, non-isothermal, transient) based on ANSYS FLUENT 17.0. The model covers different aspects such as:

- Blowing of oxygen through several injectors (supersonic) and a door lance (subsonic).
- Movement of melt, slag and furnace gas (CO, O₂) during flat-bath operation.
- Energy transfer of the electric arcs into the melt and onto the furnace walls (hot spot prediction).
- Furnace wall load (stress, temperature) and CO post-combustion inside the furnace domain.

The paper describes the CFD model and focuses on results for a 120 t AC EAF and a 140 t DC shaft-type furnace.

Applications & Galvanizing / 20**Proportional Oxygen Burner - A light, multipurpose burner for metallurgical applications****Author(s):** Mr. KRAUSE, Fabian¹**Co-author(s):** Dr. KEMMINGER, Andreas² ; Dr. VOJ, Lukas¹¹ SMS Group² SMS-Group**Corresponding Author(s):** fakr@sms-group.com

Natural gas burners are prevailing tools for a wide range of metallurgical operations. The field of usage is extensive and includes, i.e., melting of scrap in EAF, heating of slabs in pre-heating furnaces or post combustion in off-gas treatment plants. Since the invention of the Bunsen burner in 1857 the design of natural gas burners have changed substantially. Modern day burner designs like the SIS plus® and CONSO R6® are hybrid burner/injector systems and allow for multiple operation modes. During melting of scrap they are used as non-premixed natural gas burners with optimized flame length. During flat bath operations the burners are switched to injector mode and allow for a long and stable oxygen jet. In between these process sequences a pilot mode flame protects the unit from being splashed. In contrast to hybrid burner/injectors the new Proportional Oxygen (PROX) burner is a light, multipurpose burner for a wide range of metallurgical applications. The PROX design provides adjustable nozzles for the fuel and oxidizer duct, thus the flow rates can be adapted to varying process requirements and power levels, respectively. This allows the usage of this burner without a valve stand. The paper summarizes the current development status, results from laboratory field tests at a 4 MW PROX burner and accompanying CFD (Computational Fluid Dynamics) simulations as well as the potentials of the PROX burner.

Secondary Metallurgy / 21**CFD simulation of multiphase melt flows in metallurgical reactors****Author(s):** Mr. KEMMINGER, Andreas¹**Co-author(s):** Prof. ODENTHAL, Hans-Jürgen²¹ SMS-group² SMS group GmbH, R&D Division**Corresponding Author(s):** andreas.kemminger@sms-group.com

The AOD process is primarily used for stainless steel making since conventional BOF converters lead to high loss of Cr and other alloy elements due to oxidation. During the different operational stages, namely decarburization, reduction and desulphurization, an O₂/Ar mixture is fed into the converter via submerged tuyeres that can be located either in the side wall or the bottom. The O₂/Ar bubbles rise to the bath surface and cause high disturbance and intensive mixture of melt and slag thus increasing the reaction surface and speeding up the process. This paper describes how to use CFD methods to investigate the influence of different tuyere positions on the velocity field and mixing behavior of melt and slag. The developed CFD model is embedded in the ANSYS FLUENT 17.0 framework and includes a transient 3D-multiphase (VOF) domain with a DPM approach to model the gas bubbles. Selected results are shown for a 60 t AOD converter with different tuyere positions. Further examples for other types of converters (BOF, OBM) are presented as well.

Electric Arc Furnace / 22**Improved power quality and production benefits in EAF steel making by the use of modern MMC STATCOM****Author(s):** Mr. WILLEMSSEN, Niklas¹**Co-author(s):** Mr. PAYERL, Christian¹

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Electric Arc Furnaces (EAF) used for steel production are characterized by high and strongly erratic consumption of reactive power, substantial harmonic generation, as well as asymmetrical loading of its three phases. As conventional generation are being replaced by renewables the power systems will become more sensitive to these disturbances. To compensate for these adverse effects Static var Compensators (SVC) are typically installed. This paper will present recent developments in this field in terms of a general overview of MMC (Modular Multilevel Converter) STATCOM as well performance measurements from a recent installation (2016). Production benefits with a STATCOM will also be discussed like shorter tap to tap times as well as reduced energy consumption.

Rolled Properties and Characterizations / 23

Real-time 3D reconstruction and defect detection on hot-rolled steel products based on the laser-light-section method

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Abstract

In this work, we present a novel inspection technique for surface defects on cold and hot steel products during production. Common approaches for cold steel products are based on 2D images, which are highly influenced by the surface texture and thus lead to high false alarm rates on hot surfaces. Automated detection of defects on hot surfaces is of special interest, though, because it allows the manufacturer to react as early in production as possible and consequently minimize waste and labor costs.

We propose the use of high-speed light section sensors that allow a complete 3D-Reconstruction of the inspected object, even when dealing with surfaces of up to 1000 degrees Celsius. Depth-Images are already delivered by the sensors and processed to so-called Residual-Images, that encode structural deviations on the surface. The Residual-Images are then segmented in order to detect and classify defects such as cracks and flakes. As this approach is based just on the 3D information given by the sensors, it is independent of the surface texture. It also allows calculating useful defect information such as depth and volume, as well as the calculation of common profile dimensions like product height and width. This makes it possible in the future to combine the surface inspection with high accuracy profile measurement into a multi-purpose system.

Hot Plate Mill / 24

FE analysis of influence of edge wave length on roller leveling effect

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Flatness is one of the most important qualities of plates. Most plates just after the rolling or cooling process, however, do not satisfy the flatness demand for customers. As the most particular flatness defects, edge wave and center buckle are well-known.

In order to satisfy flatness limits, roller leveler is widely applied. In the roller leveling, the plastic deformation ratio that represents the magnitude of bending is the most important parameter for

its leveling effect. However, leveling effect of edge wave and center buckle sometime varies though the equal plastic deformation ratio is given in the practical operations. This work investigates and discusses the influence of edge wave length on leveling effect through a three-dimensional FE analysis.

Oxygen Steelmaking / 25

Influence of interfacial tension and viscosity on the formation of metal emulsion by rising gas bubble.

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In order to enhance the reaction rate between the slag and the metal, the formation of metal droplets in the slag phase (metal emulsion) is an effective measure. In this paper, the formation behavior of metal droplets by the bubble rupture of the gas injected into the metal phase was investigated. To extract the metal droplets, the water soluble chloride (KCl-LiCl-NaCl) and oxide (Na₂B₄O₇) were used as the upper phase and the influence of viscosity was clarified. As the lower phase, Sn and Sn-Te were used to show the influence of interfacial tension. By the sampling of upper phase during gas bubbling, the size distribution of the emulsified metal droplets, extracted by the immersion of the sample into the aqueous solution, was measured. In addition, the direct observation of the bubble detachment and droplets formation behaviors by high speed camera was conducted as the upper phase was transparent. The following results were obtained: (1) As the increase in the gas flow rate, formation rate of droplets increased. The decrease in the interfacial tension and the increase in the viscosity showed the negative effect on the formation rate. (2) The frequency of bubble rupture increased and bubble volume decreased by the decrease of the interfacial tension. (3) The dimensionless equation which showed the total volume of droplets divided by bubble volume was formulated as a function of physical properties and bubble Eötvös number to predict the droplets formation rate in the bottom blowing converter.

Hot Strip Mill / 27

Energy saving and process optimization in a conventional hot strip mill by application of the latest high-efficient descaling technology

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The paper describes the converting to a new generation of descaling nozzles in a conventional hot strip mill for steel. There are descaling stations behind the reheating furnace, on the roughing mill stands and in front of the finishing mill. Before the converting, there had been three high pressure pumps in operation to supply the descaling stations. The new descaling nozzles had been tested first in the finishing mill descaler with good results. There were considerable water savings without compromising the descaling effect and the material surface quality. After a successful test, the remaining descaling stations had been converted accordingly. The overall water savings was approx. 20

Cokemaking / 28**3D numerical model for gas and pulverized coal injection optimization****Author(s):** Mr. FERREIRA, Rodolfo Paulo Santos¹ ; Mr. PRIYADARSHI, Harsh²**Co-author(s):** Mr. GHAZAL, Ghassan ¹ ; Mr. NECHYPORUK, Oleksandr ¹ ; Mr. DAELMAN, Alain ¹ ; Mr. RAY, Shamik Kumar ³¹ *ArcelorMittal*² *ArcelorMittal*³ *CanmetENERGY***Corresponding Author(s):** rolpferreira@hotmail.com

Pulverized coal injection (PCI) is now commonly used in iron making blast furnaces to produce reductants and to generate heat in the raceway. The advantage of using this important auxiliary fuel is that it replaces the expensive metallurgical coal and, therefore, helps in lowering the operating cost of the blast furnace. The optimization of the PCI practice has led to high rates of pulverized coal injection in some furnaces. Moreover, natural gas has also been used as an additional auxiliary fuel, but its effect on the coal burnout is not very well understood yet. In this paper, a three-dimensional CFD model is described and used to simulate the trajectory and combustion performance of pulverized coal particles injected into the raceway of a blast furnace. The numerical results were first validated by comparison to an experimental setup, in which five different industrial coals are burnt in an environment with conditions close to those found in the raceway. After validation of the model, a detailed investigation in an actual blast furnace raceway is then conducted to optimize the coal burnout with high PCI rates and/or natural gas injection. Process parameters, types of coals and lance design represent the main aspects that were studied.

Blast Furnace Ironmaking / 29**New discrete element simulation for trickle flow in blast furnace****Author(s):** Mr. NATSUI, Shungo¹**Co-author(s):** Dr. OHNO, Ko-ichiro ² ; Dr. SUKENAGA, Sohei ³ ; Dr. KIKUCHI, Tatsuya ¹ ; Prof. SUZUKI, Ryosuke ¹¹ *Hokkaido University*² *Kyushu University*³ *Tohoku University***Corresponding Author(s):** natsui@eng.hokudai.ac.jp

We performed a numerical analysis for simulating packed bed structures containing non-spherical elements and the liquid trickle flow characteristics of such structures. Fully-Lagrangian numerical simulation methods can track all motion information for solid or liquid elements at each point in time. We performed individual packing behavior calculations for non-spherical elements, based on DEM with expanded functions. It is a method using a DEM contact force model that is expanded to handle the motion of freely shaped rigid bodies. It expresses complex shapes to enable low calculation costs and intuitive mounting. We used the boundary for the granular media configured with non-spherical elements to implement a trickle flow simulation based on particle hydrodynamics. Even for elements of equal volume, different shapes changed the liquid passage velocity and hold-up amount. The mean downflow velocity of the liquid phase was not always dependent on the void fraction. For the plane of projection, we obtained a good correlation with the mean downflow velocity in each packed structure, and successfully performed arrangements according to the new liquid-passage shape coefficient.

Hot Strip Mill / 30**Radar solutions for harsh environmental conditions**

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IMS Messsysteme GmbH has developed the first width measurement system based on radar technology for hot rolling mills. In contrast to laser radiation or light, radar waves are insensitive to steam and dust. Therefore, the system allows for width measurement under harsh environmental conditions, where the use of other measurement technologies is difficult or not possible at all. As the radiation intensity is low, no safety precautions are required. The system consists of two measuring units, each equipped with a sensor and a pair of antennas. The width is determined by measuring the distance between the antennas and the strip edge on each side and a suitable calibration. At first, a prototype system operating at 30 GHz was installed at the roughing stand of the hot rolling mill of Salzgitter Flachstahl GmbH. During these tests, the high robustness, measurement accuracy and low maintenance requirements under rough environmental conditions were demonstrated. Meanwhile, a 60 GHz system operating in a free frequency band was developed in cooperation with the Fraunhofer FHR. It provides higher measurement accuracies in laboratory tests due to its larger bandwidth. Besides that, implementation is facilitated by the smaller size of the antennas. The new 60 GHz-system was installed at the same position in the hot rolling mill as the prototype, so that the performance of both systems can be compared. After finishing the field tests by the end of 2016, the 60 GHz-system will be used for accurate width control at the roughing stand. In this talk, the principle and setup of the radar width measurement system are presented. The results obtained with the new 60 GHz-system in laboratory and field tests are shown and compared to the prototype.

Advanced Rolling / 33

Broadening the steel markets by direct application of high quality ESP strips

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The flat steel feed stock for final fabrication of steel products is mainly covered by cold rolled and final annealed or galvanized strips. Depending on the thickness and surface demands, also conventional batch processes can serve a certain but truly very limited ratio. The Arvedi ESP Technology is giving new impulses into this market. With this game changing technology it is suddenly possible to serve feed stock for numerous applications, which can't be directly produced by hot rolling until now. Thinner and at the same time wider steel strips can be produced and are able to replace a high amount of cold rolled steel strips. Joint development efforts by Rizhao Steel and Primetals at recently started up ESP lines are setting new standards to cover also even more critical products for higher applications. The paper is giving an overview of results and products developed for direct applications.

Advanced Rolling / 34

ARVEDI ESP: The technological contribution for performance optimization

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For every single final product you can get a carbon foot print, which is dominated by raw materials and production processes. The steel industry is looking to minimize its carbon footprint by self-defining reasons not only for environmental aspects, but also to cut own energy costs. There were significant results reached by optimizing each process step and also in trying to link single process steps. The Arvedi ESP technology is the first technology, reducing the energy consumption for the process of hot rolling itself by using all advantages of the fully endless production process. Furthermore it is possible to gain even higher energy reductions by either completely cutting the production route of cold rolling and annealing processes, or by optimized combination of them. This generic approach is leading to totally new production processes and concepts. This paper will give an overview of different processes and energy saving potentials oriented on final products and their applications.

Rolling / 35

Advanced roll-gap lubrication solutions in hot and cold rolling

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The need for more effective and flexible roll-gap lubrication technologies in hot- and cold-rolling mills is steadily increasing due to ever-greater requirements placed on the rolling process and the final products. This paper focuses on two innovative technologies for highly efficient roll-gap lubrication for hot and cold rolling.

For cold rolling mills, MQL® (a new generation of roll gap lubrication technologies) was successfully installed and commissioned at ThyssenKrupp Steel Europe's tandem cold mill No.1 in Bruckhausen. MQL® replaces the conventional roll gap lubrication system with emulsion in mill stands 1 and 2 by applying minimum amounts of pure rolling oil finely atomized with pressurized air directly onto the work roll surface. As a consequence of the improved lubrication efficiency, rolling forces, motor torques and energy consumptions could be reduced and the strip surface cleanliness was significantly improved due to reduced strip wear in the first stands of the mill.

For hot rolling mills, a solution concept for removing residual oil from the work roll surface is presented. In a typical hot rolling mill, the work roll lubrication (WRL) in a specific finishing mill stand is switched on a sufficient time after thread-in of the strip head and is switched off early enough before thread-out of the strip tail in order to prevent too low friction and violation of the bite condition. Due to an efficient cleaning procedure, the presented concept ensures safe thread-in independent of the lubrication conditions of the previously rolled strip.

Cold Rolling Mill / 37

Tangshan new #2 cold rolling mill complex to produce advanced high strength steels for automotive market

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Primetals and Tangshan have achieved a great performance in project execution to enable a fast development of Tangshan's new #2 Cold Rolling Mill Complex dedicated to the most valuable products in cold rolled, annealed and coated coils.

The project was not limited to equipment delivery and line start-up but included challenging steps in production while considering the three processes, cold rolling, annealing and coating requesting a great experience in all processes, reliable technology, to enable performance in production throughput and quality as per market expectation.

The time-to-market key milestone was achieved successfully thanks to a fast project implementation which confirmed first coil within the targeted period of twenty one months after contract effectiveness, along with an efficient commercial production ramp-up in Pickling Line Coupled to a Tandem Cold Mill (PLTCM) and straight forward in Continuous Annealing Line (CAL) and Continuous Galvanizing Line (CGL).

The single project responsibility under the lead of Primetals Technologies was in favor of smooth and simplified communication route with Tangshan's team, but also gives great benefit to the operator and maintenance crews due to many commonalities in equipment design and good practice in operation and maintenance.

In addition to the process equipment delivered, a Know-How Package from up-stream to finishing production stage has been integrated in the contract to bring steel production and plant organization robustness, and covering the new steel grades and especially for AHSS.

The combination of Primetals Technologies expertise in equipment, process and Know-how, associated to Tangshan experience in steel field brought a fast success already recognized on the Chinese market by Tangshan's clients and the certification dedicated to the most valuable products.

Hot Strip Mill / 38

The most unique hot strip mill in the world

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In June 2010, after almost three years of intensive preparation work and intense technical discussions, PRIMETALS TECHNOLOGIES (PT) received an order from Allegheny Technologies Incorporated (ATI) to design, engineer and supply a new, fully integrated hot-rolling mill on a process-turn-key basis which included a water treatment plant. PRIMETALS successfully executed this project by using the interaction of different in-house engineering locations for mechanic/fluid (Austria-Linz and USA-Canonsburg) and electric/automation (Germany-Erlangen and USA-Alpharetta).

The mill is capable of rolling a wide range of highly diversified carbon and stainless steels and specialty metals at widths up to 2,083mm. The rolling forces are the highest ever to be supplied for a hot-strip mill allowing ingot to coil, ingot to slab and slab to coil (incl. slab to plate) production.

ATI embarked on this strategic investment in order to shut down an old hot rolling mill which operated since the 1950's, to enhance its production capabilities, to strengthen their top-position in the market and to handle future material developments. This advanced specialty metals hot-rolling and processing facility (HRPF) has been in operation since late 2014 at ATI in Brackenridge, Pennsylvania, in the United States.

The new facility is designed to produce a unique and very diverse product mix that includes flat-rolled austenitic, ferritic and martensitic stainless steel alloys, grain-oriented electrical steel, titanium and titanium alloys, nickel-based, corrosion-resistant and high-temperature alloys, zirconium alloys, and other specialty metals. The rolled and processed products are used in the aerospace, automotive, defense, petroleum, chemical, construction, mining and power industries, as well in various medical, food-equipment, machine and cutting-tool applications. Carbon rolling (e.g. API grades up to X100, Dual Phase grades) is also within the overall capability of this unique mill.

An overview of the most powerful hot strip mill as well as impressive operational results and project highlights will be presented in the paper.

Rolled Properties and Characterizations / 40

Inline measurement of electromagnetic parameters for characterization of material properties of steel strip with a focus on magnetic values

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Inline measurement of mechanical and magnetic properties of steel strip with contactless, non-destructive techniques offers considerable potential for further technological optimization and new applications. This is achieved by the PropertyMon system from Primetals Technologies employing state-of-the-art methods for indirect measurements using electromagnetic signals. By measuring the hysteresis curve of the steel strip, mechanical and magnetic properties can be calculated applying regression calculations. The required coefficients are obtained via regression analysis of test measurements and corresponding laboratory samples. This method gives reliable results for e.g. tensile strength, yield strength, hardness, magnetic losses and magnetic polarization.

Recently, test trials to determine magnetic power losses P and polarization J were carried out at an annealing line of thyssenkrupp Steel Europe in Bochum, Germany, for non-grain oriented (NO) electrical steel. This article presents test results for these magnetic parameters which are of importance especially for electrical steel strip production processes. Continuous calculations of P and J can be achieved with a high degree of accuracy for online process monitoring and quality control.

Remarkably, the PropertyMon system exhibits some unique features such as the simultaneous detection of mechanical and magnetic properties, directional measurements for anisotropic properties, and space-resolved measuring via traversing of compact sensors over the strip width. Therefore, this approach complements or outperforms standardized destructive laboratory testing procedures in many ways.

Cold Rolling Mill / 41

Performance Modules – a convenient and sophisticated way for cold rolling mills

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Yield and economy during cold rolling of flat products depend on developing high capacity components fulfilling further increasing customers demands for cost and resource effective production of steel strip material. The paper gives an overview of the latest developments for high capacity components and tools of SMS group for cold rolling tandem mills and cold reversing mills. The SMS components cover the fields' mill mechanics, electric and automation as well as mill reliability and customer strip quality figures in case of modernization tasks as well as erection of new mills. Regarding cold strip mills the topics according to material flow are treated as follows:

- TRC® rolling assistance system with mechanical roll gap measurement in the strip entering phase. Using the roll gap assistance system results in an increase in yield of up to 1.5% due to

reduced off-gauge weight. • High Torque spindles for the mill train drives transmitting rolling torques even using smaller work roll diameters or an extended mill capability for more demanding grades in existing mills with space restrictions. • Ultra-Low Vibration Gear (UVG) with advanced gear geometry to eliminate drive oscillation and vibrations and to reduce chatter marks even at higher rolling speeds. • Twin reel – carousel tension reel with an operator and drive side supported mandrel providing coiling of extended product mix and increased coil eye stability. • New generation fume exhaust system giving a reduced exhaust in the interstand area fulfilling strictest environmental demands.

Further the topics Industry 4.0 applications and PQA-techniques for thoroughgoing quality assessment in cold rolling mills are discussed.

Key words: Cold rolling tandem and reversing mill, Industry 4.0, PQA, mill modernization, mill erection, high capacity mill components

Hot Strip Mill / 42

Performance Modules – a convenient and sophisticated way for hot rolling mills

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Yield and economy during hot rolling of flat products depend on developing high capacity components fulfilling further increasing customers demands for cost and resource effective production of steel strip and plate material. The paper gives an overview of the latest developments for high capacity components and tools of SMS group for conventional hot strip mills, CSP® plants and heavy plate mills. The SMS components cover the fields' mill mechanics, electric and automation as well as mill reliability and customer strip and plate quality figures in case of modernization tasks as well as erection of new mills.

Regarding hot flat strip mills the topics according to material flow are treated as follows:

- New designed slab and strip descaling systems equipped with frequency controlled valves and maintenance friendly top and bottom header design,
- Rigid hydraulically driven heavy side guides for centering actions enabling camber and wedge free rolling of transfer bar and final strip,
- Heat cover hoods with individual change able heat panel elements providing less maintenance effort and extended reliability,
- Torque spindles for the finishing train drives transmitting rolling torques even using smaller work roll diameters,
- Compact Roll Cooling System based on forced convection principle,
- Assistant system for proper leveling the finishing train stand screw actuators to prevent strip tail end chewing during feeding out causing roll and mill stand damages,
- Reinforced and super reinforced laminar cooling headers providing higher cooling rates for processing steel grades with advanced mechanical technological properties and
- Asymmetrical acting strip edge masking system controlled by the strip tracking behavior on the run out table protecting over cooling of the strip edges and flatness defects.

For heavy plate mills the multi flex quench system was developed fulfilling necessary cooling rates for processing plates with advanced mechanical properties for more sophisticated applications.

Finally the topics Industry 4.0 applications and PQA-techniques for thoroughgoing quality assessment in hot flat rolling mills are discussed.

Key words: Conventional hot strip mill, CSP® mill, Heavy plate mill, Industry 4.0, PQA, mill modernization, mill erection, high capacity mill components

Cost & Process Control / 43

Comprehensive competence in beneficiation technologies – from the raw materials to steel

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The efficiency of the iron and steel production becomes increasingly a very important factor for any producer in the world. Looking at the overall costs for steel production, the source and quality of iron ore is the most important factor, which influences the overall efficiency downstream to the steel making process. By improving the iron ore quality the entire processing chain benefits because the separation of the impurities accounts for a significant portion of the processing costs in the blast furnace or the melt shop, where the impurities are separated in form of slag, which requires thermal respectively electric energy.

In order to accommodate with these requirements Primetals Technologies intensified recently the activities in the field of beneficiation and developed in parallel a single calculation model, which considers the complete chain of processing plants from the incoming raw materials to the liquid steel with the accuracy of a specific mass balance for any of the individual plants.

In addition efforts have been made to investigate upgrading of dumped tailings to produce an extra concentrate in order to increase the overall recovery of the valuable iron minerals. With the holistic evaluation of the iron and steel making process Primetals Technologies is now in the position to offer all available industrial scale proven plant types from run of mine and even from tailings to liquid steel including beneficiation as single units and also to calculate the complete processing route in one model in order to achieve highest efficiency and lowest processing costs of an integrated iron and steel works.

Sintering & Pelletizing / 45

Efficient and environmental friendly sinter-cooling based on the counter flow principle

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State of the art sinter coolers are working based on the cross flow cooling principle. Thus, only a part of the thermal energy can be used for heat recovery application. The other part of the cooling air is brought unused to the environment. Furthermore, environmental regulation regarding dust emission and intelligent usage of exergy are getting stronger.

Therefore Primetals Technologies developed sinter coolers based on the counter flow principle. The cooling air passes the sinter bed in counter flow direction enabling a direct heat transfer from the hot sinter to the air. The exhaust air temperature can be maximized by using the total heat of the hot sinter. Due to the possible usage of the total exhaust air amount, diffusive dust emissions are reduced to zero.

Two types of counter flow coolers are in the portfolio of Primetals Technologies. One type is based on a stationary shaft, into which the hot sinter is charged. The flow of the hot sinter is in vertical direction from top to bottom, in counter direction than the cooling air. The second type is a circular hopper cooler. The hot sinter is charged on top of a moving bed. At the bottom of the bed the sinter is discharged. The cooling air flows also from the bottom to the top, following the counter flow principle. These coolers are already in operation in Japan. Depending on the requirements, one of the two counter flow coolers types can be chosen for optimized and efficient cooling of hot sinter.

Primetals Technologies offers energy-efficient and environmentally friendly sinter cooling solutions by means of counter flow coolers, either a shaft cooler or a circular hopper cooler.

Sintering & Pelletizing / 46

Numerical simulation of sinter process and optimization of top burner system by CFD simulation

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Decreasing iron ore quality, higher substitution rates of main iron ores to cheaper raw materials due to economic pressure and increased environmental standards are constantly challenging the iron and steel producers. Changing the raw materials in an operating plant can significantly influence the sintering process. Adjusting all process parameters to regain stable and high productive operation takes considerable time and causes production losses. Furthermore changes in raw materials lead to variations in the process gas flows and emission concentrations.

Therefore Primetals developed a model for numerical simulation of the sintering process. The sinter simulation model simulates all solid and gaseous flows during the sintering process. The influencing factors of the sinter process are implemented in the simulation tool either as input values (e.g. chemical composition of raw materials), boundary conditions (e.g. suction pressure) or calculation results. The simulation is highly flexible for different process scenarios and based on the integrated calculation models allows a more accurate prediction of process parameters and sinter off gas emissions.

Furthermore Primetals Technologies has intensified their activities in the field of Computational Fluid Dynamics (CFD) for an optimized design of the top burner system. The CFD software simulates not only the burner flame itself but also the complete combustion process within the whole ignition furnace and annealing hood. These results can be used for confirming engineering results and if required for changes of engineering in a very early point of project execution. This numerical simulation is well-established and a cost-efficient alternative to test series in laboratory scale.

Cost & Process Control / 49

TSL KPO BF 1 – Design, commissioning and start-up

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In 2012 Tata Steel Ltd, commenced construction of an integrated iron and steel plant in Kalinaganagar Orissa, India. The first phase of the project included steelmaking facilities, coke plant, sinter plant and blast furnace number 1. A contract had been awarded to Primetals Technologies in January 2007 to design and supply the new 14m hearth diameter blast furnace and additional facilities as part of the overall site arrangement.

The project included the supply of equipment required for a modern free-standing blast furnace including a copper stove cooling system, a flat floor casthouse arrangement, bell-less top charging facilities, and a full suite of blast furnace unit equipment. Also supplied were wet slag granulation facilities, three external combustion chamber hot blast stoves and a gas cleaning plant with top gas recovery turbine arrangement. The blast furnace blow-in occurred on the 29th February 2016 and has design capability to supply up to 9,150 tons of hot metal per day.

This paper will discuss the project scope and highlight some of the design features such as pneumatic dust conveying, cyclone and dustcatcher combination, trough forced cooling, latest stove crossover design. Some of the challenges faced through the various phases of the project (design, supply, construction, commissioning and operation) will also be reviewed.

Oxygen Steelmaking / 51

Fully automatic converter steelmaking

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The intensive use of automation solutions, process models as well as expert systems is well established in converter steelmaking. and It is widely recognized that automated procedures have a positive influence on productivity, product quality and operational safety. The combination of existing technologies, new support systems and the beneficial use of information management tools empower the plant operator to run the plant in almost fully automatic manner, where operators can concentrate on supervision and optimization of the process.

Within this paper a bottom-up approach including reference examples how a steel plant can be upgraded in a way that the BOF production can be executed in an almost fully automatic manner is presented. The approach consists of several steps beginning with basic automation requirements like fully automated transfer cars and reliable measurement systems, more advanced automation solutions like robotics for probe handling or crane logistics for fully automated charging and ends with full coupled data management systems for through process quality control. First practical references like the ICE TAG technology, a high temperature RFID-based identification technology for ladles and slag pots as well as monitoring, Lance Guard for closed loop diagnosis of sublance measurement system, or Fluid Guard for leakage detection in safety critical applications are presented. The approach includes further condition monitoring systems to ensure highest plant availability and reliability with lowest maintenance costs. Finally, solutions for automation of most important maintenance tasks in converter steelmaking like lining maintenance or converter relining are discussed.

Oxygen Steelmaking / 52

Optimization of converter design with CFD – Practical application for converter revamp

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Numerical flow simulations have constantly evolved in the last decades and nowadays play an important role in the development of modern converters. The flow inside the converter is highly complex and comprises a whole lot of physical phenomena like supersonic flow, chemical reactions, heat transfer and the flow of gas bubbles in the liquid melt. Due to numerical reasons, not all flow processes can be taken into account, but it's possible to capture major effects, show tendencies and gain valuable knowledge on multi-phase flow processes inside converters. Subsequently the results of these analysis will be used in the design of new converters.

Primetals Technologies has committed itself to develop an efficient approach for modelling the flow and mixing inside the bath during the refining process within reasonable time. In an exemplary manner, a 110t converter was examined and evaluated concerning mixing. A generally applicable method for modelling the flow and quantification of the mixing intensity has been built up. It became clear that there are 2 kinds of vortexes generated inside the flow which are of importance for mixing and global flow. On the one hand there are vortexes formed near the bubble columns at the stirring elements and on the other hand much bigger vortexes which strongly influence the global flow in molten steel bath were observed. Furthermore it was shown that the arrangement and type of the bottom purging elements is a crucial design aspect for the mixing intensity. Especially asymmetric alignment of purging elements produces critical regions with very low local flow velocities.

In addition Primetals Technologies has used its full numerical simulation competence to investigate the influence of varying process parameter at converter top blowing, like input pressure drop, to optimize the blowing lance equipment.

Slags / 53

Boosting the value of your steelmaking slag and dust**Author(s):** Mr. WIMMER, Gerald¹**Co-author(s):** Mr. FLEISCHANDERL, Alexander ¹ ; Mr. PASTUCHA, Krzysztof ¹¹ *Primetals Technologies Austria GmbH***Corresponding Author(s):** georg.krempf@primetals.com

Considerable amounts of slag and dust are produced in integrated – iron ore based – steelmaking as well as in EAF – scrap based – steelmaking. These by-products still contain considerable amounts of metals in metallic and oxide form and are nowadays only partly processed and recycled, the rest has to be landfilled. Typical solutions are internal recycling via the sinter plant and the blast furnace, briquetting and charging to the BF, BOF or EAF as well as mechanical processing and low value external applications like road construction or filler materials.

Primetals technologies developed an innovative process that allows reduction of all metal oxides in the slag or dust, collect the metal phase and bring all metals back into the main process. The remaining mineral fraction can be modified if necessary with respect to its basicity to allow its usage as a high value material in the cement and binder industry. For example slags from converter steelmaking processed this way can be directly used as a high value cement clinker substitute, while the metal recovered is dephosphorized and used as hot metal or scrap substitute in the converter. The process itself takes place in a modified electric arc furnace with coal injection and quasi-continuous liquid slag charging.

In the paper the process principles including different ways of utilization of the mineral fraction are shown together with business cases – for an integrated steel plant for carbon steel production and for and EAF processing mainly DRI.

Secondary Metallurgy / 54

Upgrade of stainless and special steel production by implementation of AOD process at ACRONI**Author(s):** Mr. VORABERGER, Bernhard¹**Co-author(s):** Mr. PASTUCHA, Krzysztof ¹ ; Mr. WIMMER, Gerald ¹ ; Mr. ADLEFF, Alexander ¹ ; Mr. ROBIC, Roman ²¹ *Primetals Technologies Austria GmbH*² *SU Acroni***Corresponding Author(s):** georg.krempf@primetals.com

In mid of 2015 Acroni, a Slovenian steel producer belonging to the Slovenian Steel Group (SIJ), has awarded Primetals Technologies with an order to supply a new 95 metric ton AOD converter and dedusting system to its steel works in Jesenice. Less than 2 years later, in April 2017 the new process route will be brought into operation resulting in an increase in annual liquid steel production capacity up to 650.000t. Until now, the crude steel has been produced in an electric arc furnace, and decarburized in a VOD converter with a capacity of 90 metric tons. As the duration of treatment is significantly longer than for carbon steels, this plant configuration represents a bottleneck in the stainless steel production that will be eliminated by installing an AOD converter, which will increase both the production capacity and the flexibility of the steel works. Heat processing times for stainless steel can be reduced significantly, e.g. 55min faster tap to tap times at the furnace are possible and more than 2 hours can be saved by replacing treatment at VOD with the new AOD for duplex and ferritic grades. Additional advantages of an AOD converter are the low degree of slagging of alloying elements, such as chromium, and the option of using cheaper ferrochromium grades with an higher carbon content as an alloying addition. Therefore production costs can be reduced for Acroni with results in short payback time of the AOD investment.

Latest state of the art technologies have been installed by Primetals Technologies at Acroni's melt shop like the new material handling system and process automation system specifically

designed for AOD converters. This ensures that raw materials are used efficiently, and minimizes treatment times. In addition the converter is equipped with a patented Drive Damper system to reduce the vibrations caused by the injection processes, which results in reduced wear and maintenance costs, while also lengthening the service life of the plant. The dedusting system, which will be installed at the same time as the AOD converter, will not only ensure that emissions are below the current limits, but also increase the energy efficiency and occupational safety in the production environment.

In the paper the technical highlights of the project will be summarized as well as project execution and results achieved.

Cokemaking / 55

Briquetting of ferrous and coal fines – Saving resources, creating value

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One of the global trends that are constantly challenging the iron and steel industry is related to the generation of fines, slurry, sludge and scales, summed up as ferrous by-products. The recycling of those by-products is commonly practiced in many steel plants. These materials normally cannot be used directly in the primary processes. The most common application is to add ferrous by-products which are suitable concerning chemical composition and grain size distribution to the sinter mix. Besides addition of fines to the sinter plant, other solutions exist. Primetals will present latest developments in the field of cold briquetting of ferrous by-products. Giving examples and results of executed project(s) of cold briquettes directly fed to the DR shaft, and other solutions for integrated steel mills.

Coal briquetting on the other hand is based on coal fines which often originate from wear during coal transport from mine to plant. These fines can be used to produce briquettes designed either for the use in a smelting reduction process (COREX®/FINEX®) or for enhanced coke oven operation in the traditional blast furnace route.

Primetals coal briquetting targets at the production of coal briquettes superior in mechanical properties and hot strength. Their application aims at an increase in productivity and reduction of costs. In the paper, Primetals will show different scenarios and solutions for coal briquetting technology.

Oxygen Steelmaking / 56

Slagless technology - New BOF performances at GERDAU OURO BRANCO

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This work was a continuous development and multidisciplinary. Through the blowing process survey data and process parameters being conducted developments, enhancements and adjustments at lance tip hot face parameters with Slagless technology, as well as blow process

parameters, reestablishment system " autopilot " blow and mitigating actions for slopping. The main results are Increased tip life with the record mark 1785 heats blowed, drastically reducing water leaks occurrence in the cartridge and lance, stability blow settings function in dimensional nozzles adjustments for this specifically steel shop.

Oxygen Steelmaking / 58

TIP lance nozzle wear study at VALLOUREC BRAZIL BOF

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Oxygen blowing is the main operation in the steel refining process in BOF (Basic Oxigen Furnance) steelmaking. This blow is made by an oxygen injection lance through supersonic nozzles, which must be designed for the specific operating conditions, such as flow and oxygen pressures, height in relation to the metal bath, lance height, etc.. Bad design of these nozzles directly influences the time and process efficiency, and often results in premature wear of the nozzles and their removal from production. This type of failure has been observed in tip nozzles in Vallourec Brazil. This work presents a methodology of studies and results of metallography in samples of tips used by Vallourec Brazil, in addition to CFD (Computational Fluid Dynamics) simulations of the gas jet. This information was used as a basis for the redesign of the nozzles, in order to reduce the impacts caused by wear.

New Ironmaking Technologies / 59

Commissioning and first operation results of world largest voestalpine Texas Midrex HBI Plant

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After a short decision making process voestalpine Stahl Linz decided in June 2013 about their largest foreign investment project for the installation of a 2.0 MTPY Midrex HBI plant in Corpus Christi, Texas/USA. A consortium of Primetals USA LLC and Midrex Technologies was awarded for the supply of Equipment, Engineering and Technical Services of the Direct Reduction plant as green-field project.

The Midrex plant which consists of a 7.15 meter reduction shaft and a 20-bay reformer has an annual production capacity of 2,000,000 tons. The hot briquetting system is equipped with a hot fines recycling system. The cooling of HBI is done by cooling conveyors. The produced HBI with an average metallization degree of 93% and 1.5% carbon content will be shipped to voestalpine's steelworks in Austria and sold to the North American market.

After current commissioning activities including integrated plant tests and dry-out the Midrex plant will be started up in the third quarter of 2016. This presentation will cover the main commissioning steps and the first operation results of the world largest HBI plant.

Environmental / 60

Future of direct reduction in Europe – Medium and long-term perspectives

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Driven by the global megatrend of CO₂ reduction and improvement of energy efficiency there is also shift of energy systems ongoing which will also influence the way of steel production in Europe. The EU roadmap for a low carbon economy suggested even a reduction of CO₂ emissions of 80% between time period from 2005 to 2050.

New CO₂ lean iron making technologies like natural-gas based direct reduction plants for production of DRI/HBI utilized for steel making are considered as medium-term possibility for reduction of CO₂ emissions by more than 60% of process-related CO₂ emissions. Some European steel producers like voestalpine are going to produce HBI at locations with cost-effective availability of natural gas and at the same time reduce process related CO₂ emissions by utilization in their own steel works.

In order to achieve the targeted EU reduction path in CO₂ intensity also the additional or sole use of hydrogen from renewable natural resources for iron & steel making is required on the long-term. Direct reduction is also an ideal, high-efficient and well-proven technology for utilization of hydrogen for DRI/HBI production as basis for steel making preferably on the basis of electric arc furnaces with additional synergy potential like hot transport between DR plant and EAF.

Oxygen Steelmaking / 61

BOF cold model - Metal slag bath mass movement determination by supersonic blow from multi nozzles

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The primary control tool of the BOF process lies on the adjustment of the oxygen blow parameters. The best process conditions involve several variables, like oxygen flow rate, distance bath lance (DBL), number of holes for the oxygen blow, among other factors. Through a visual inspection of the jet penetration and the volume of stagnant zones, the behavior of each configuration tested was analyzed using different sets of nozzles (3 to 6 holes), and with constant distance bath lance (DBL) and flow rate. The analysis of the interaction parameters between the oxygen blow, the molten metal and slag, represented respectively by water and paraffin oil, is the main objective of the present work. It was necessary to develop a new methodology in order to determine the penetration, propose a new formula and adjust the empirical constant, called K factor. The highest penetrations were achieved for the nozzles with 3 and 4 holes. The lowest penetration and the highest volume of stagnant zones were represented for the configuration of 6 holes.

Oxygen Steelmaking / 62

BOF lance TIP mult nozzles coalescence trigonometric study

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In the present work, an analysis of geometric parameters of tip nozzles in operation was developed and extrapolations for futures situations were proposed. The main trigonometric relationships to evaluate the possibility of jet coalescence were determined. The results showed that the Primary Circle Diameter (PCD) is not affected only by the geometry of the nozzle, tips with up to 04 (four) nozzles and small angle with the vertical can promote coalescence and tips with more nozzles than four reduce this possibility. This work also presents a relationship between number of nozzles and angle between two adjacent nozzles. An important tool to determining conditions for development of new tips lance is proposed.

Oxygen Steelmaking / 64

Innovative solutions for BOF dedusting systems – Achieving minimum emission levels

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Environmental protection has become more important in the iron and steel making industry during the last few decades. Stricter environmental protection measures are now required to comply with regulations set by government agencies. Dry dedusting systems (DDS) represent the latest technology for cleaning the primary gas of basic oxygen furnaces (BOF). Due to increasing economic pressure on the steel and iron making industry, DDS with relative high investment costs have become less attractive.

Therefore Primetals provides cost efficient dedusting solutions for steel plant operators.

As an alternative to the DDS, investment friendly solutions for revamps of widely applied wet dedusting systems (WDS) are provided. A new application is the wet electrostatic precipitators (WESP) downstream of WDS. The WESP can handle the typical particulates with water saturated primary gas and reduce the dust emissions. Furthermore the installation in a bypass shortens the shut down time for the rebuild. A further innovation is a new scrubber design to increase the gas cleaning efficiency. The separation efficiency is enhanced due to a water injection at an angle of 45° against the gas flow.

The implemented innovations and improvements will be presented in detail and the results achieved will be discussed.

Cost & Process Control / 65

Integrated steel plant optimization in flow sheeting process integration platform

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Iron and steel making requires a wide range of different raw materials significantly influencing process performance which demands a continuous optimization of process routes also with respect to energy efficiency as well as environmental emissions. Steadily changing raw material prices

and qualities, market situations and product variations are challenging integrated steel plant operators in production planning and cost optimization.

In terms of investment planning, detailed knowledge and comparison of possible process routes is necessary. For greenfield investment decisions, a robust comparison of available processes is essential considering all site conditions and raw material specifications. For brownfield investigations detailed knowledge about existing process routes and comparison to desired ones is requested.

Up to now steel industry experiences a lack of the possibility in generating robust overall mass and energy balances covering integrated steel plants, concerning both operators and engineering companies.

Detailed evaluations by Primetals Technologies proved this situation and led to the development of a holistic metallurgical model library in a flexible flow sheeting environment. This publication will give an introduction to the iron and steel making process integration platform.

Gas Cleaning / 66

Towards a cleaner future - Trends in gas cleaning technology for ironmaking

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Traditional approaches to blast furnace gas cleaning using wet scrubbers are being challenged by the re-emergence of dry gas cleaning technologies based on the success of the same in other parts of the iron and steel network.

The wet gas cleaning of blast furnace gases offers a proven solution to the handling of the process gases removing dust and certain trace contents in the gas in a single step. But the use of wet gas cleaning involves the necessary step of cleaning the water of evolved solids and then treating these solids. Blast furnace upgrades represent an opportunity to consider the enhancement of the total existing wet systems and this paper will review how these can be implemented in a cost effective manner.

Technologies to remove nitrous oxides (DeNO_x) are widely spread in many high temperature processes; as stricter regulations and more stringent emissions limits need to be met the SCR (Selective Catalytic Reduction) technology will find more usage in the future.

The paper gives an overview about the implementation of the SCR technology in sinter plants and about the special considerations that need to be respected.

Environmental / 67

Sinter plant and basic oxygen furnace waste heat utilization – New configuration with ORC modules for power generation

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The demand for increasing energy efficiency and CO₂ reduction is one of the global megatrends of our time. Although the steel industry suffers from a volatile economic environment, the steel

plants are interested to find opportunities for sustainable cost reduction and put efforts into healthy solutions for the environmental. Integrated steel plants are trying to cut electrical power and energy costs as these are among the biggest cost factors that can be influenced and taking all the advantages they can.

For the integrated iron and steel making route the interaction of waste energy utilization along with process energy demand, natural - and metallurgical gases, steam- and heating systems as well as power generation has to be considered. Potential energy sources, such as sinter plant, basic oxygen furnace (BOF) cooling stack or reheating furnaces can be analyzed in order to elaborate an integrated energy concept. When direct local use of waste heat is limited, the best option is to convert it to mechanical/electrical power with a Rankine Cycle.

Especially electric power generation is an attractive option for steel plant operators since it can easily be connected to the existing power grid of the steel plant. A stand-alone system, compact design with minimum operational costs in order to fit into the existing steel plant layout, are the main requirements of such units.

The objective of this paper is to demonstrate economic feasible opportunities for energy recovery for sinter cooler and basic oxygen furnace with focus on electric power generation via ORC modules taking at the same time advantages of CO₂ reduction by utilizing waste heat from the process. Furthermore typical arrangements and layouts of such solutions as well as basic economic calculations will be presented in the paper.

Byproducts / 69

Carbon recycling at its best – Utilization of by-products from process-gas fermentation

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Technological solutions, to utilize process gases from the iron and steel industry, to allow other production facilities, e.g. chemical industry, to use such energy sources, is becoming more and more attractive. One possible way, to convert the available energy from carbon and hydrogen-rich off-gases, such as coke oven gas, blast furnace top gas, direct reduction gas and also converter BOF gas into liquid based energy sources, is the use of a microbiological based process.

Primetals and LanzaTech offer a special process gas microbial fermentation system, to produce preferably ethanol or other chemicals. To produce ethanol, an integrated fermentation system with additional downstream installations is required, with the main target to treat the fermentation product and waste streams. The treatment of the fermentation waste streams results in a number of by-products, usable for internal or external applications. By returning the by-products to an integrated steel plant, the fermentation system can be operated as a zero waste application and compensates portions from external added input materials e.g. natural gas or carbon based materials.

Energy Management & Recovery / 70

Waste heat recovery for EAF – Innovative concepts & industrial implementation

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Over the last years, waste heat recovery in steel industry attracted more and more attention. Environmental regulations, public funding as well as required revamps of old dedusting systems lead steel plant operators to discuss and to evaluate possibilities of recovering waste heat.

The development of a waste heat recovery plant requires extensive knowledge as well as long experience of the entire plant, including water-steam cycle as well as EAF process, dedusting system and downstream waste heat consumers. Primetals provides innovative and reliable waste heat recovery solutions for EAF which are presented in this paper. An innovative waste heat recovery plant is introduced which was installed at ARVEDI / Italy. Waste heat is used to produce steam for two pickling lines, which are in a large distance to the EAF. The substitution of the existing gas fired boilers lead to a decisive reduction of operating costs of the steel plant. A heat recovery plant was installed at steel plant HÖGANÄS / Sweden, whereas hot water at high pressure is produced and utilized for the local district heating system.

The industrial implementations of waste heat recovery systems for EAF will be presented in detail and operational results achieved will be discussed.

Blast Furnace Ironmaking / 71

Installation of a dry slag granulation pilot plant at blast furnace A of voestalpine

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Blast furnace slag with its tapping temperature of around 1,500°C and a approximately 400 million tons yearly worldwide production is a huge largely unused energy potential. Current state-of-the-art practice is to granulate blast furnace slag in wet-granulation plants without utilization of the thermal energy. However new dry slag granulation technologies are in development to cool the molten slag with air and recover the thermal energy for applications like steam production or electricity generation.

PRIMETALS and its partners with their gained experience with dry slag granulation test facilities and research programs are taking the next step. A pilot plant for granulation blast furnace slag directly connected to the cast house floor of blast furnace A of voestalpine is under construction. Close to industrial scale slag granulation capacity, the pilot plants aim is to granulate slag with rotating cup technology to a valuable product under dry conditions - cooled by air. The high temperature off gas of the plant will have potential for doing highly efficient heat recovery. Extensive tests with this pilot plant should give the last technical expertise that is needed before going forward with commercialization of the process. An insight in plant arrangement, progress of erection and expectations of the pilot plant operation process will be given.

Industry 4.0 / 72

How technological advancements in proactive and predictive maintenance can increase the lifecycle of plant equipment

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Maintenance is gaining more and more attention in the steel industry as companies realize that it is critical to monitor the condition of assets to increase plant availability and reduce the risk of an unplanned shutdown.

Due to global overcapacities, modernization investments have been reduced, pushing plant equipment to its maximum lifecycle level. To reduce unplanned shutdowns, increase operational availability, and increase plant performance, steel producers are turning to the latest maintenance concepts and technologies. An integrative solution with monitoring functions for complete mechatronical packages such as caster, converter, mills, processing lines and others can be used to monitor critical equipment or processes that can cause bottlenecks in the production chain. The condition monitoring from Primetals Technologies includes evaluation of mechatronics, technological controls, process models, and third party systems as well as a lifecycle service concept. Examples from upstream and downstream part from metallurgical plants will show how an intelligent monitoring concept can be used to supervise an advanced production.

Gas Cleaning / 74

Advantages of Axial Cyclone Vs inertial spark arresters along the EAF secondary ducts: field experience and future developments through CFD analysis

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The installation of a spark arrester prior to the EAF's off-gas filter has become common practice for prolonging filtering bag lifetime as carbon injection was increased. The Axial Cyclone efficiency has been optimized by sophisticated CFD programs in recent projects to achieve sufficient abatements starting from 125 microns whilst simultaneously maintaining pressure drops to below 1" WG. Unlike parallel piped boxes, the centrifugal separators have more "wet" surfaces to absorb gaseous peaks generated by scrap charging fireballs. The recent developments obtained by CFD, associated with the new conical shape and optimized blades, could achieve savings of up to 5 kWh/tls when substituting not optimized spark arresters

Industry 4.0 / 78

Rolling into the future by digitalization

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Today's steel producers face the dual challenge of ensuring on-time delivery and ever demanding product requirements while also running a lean operation. Every day the management of a long rolling plant requires continuous optimization of both operating and business practices.

Utilizing the evolution in technology (data collection, communication, internet of things, control techniques and intelligent sensors) there is more information available than at any other time, utilizing this information and monitoring the plants performance will revolutionize the control of Long rolling mill plant worldwide, this will lead to the optimization of the entire value chain along with advanced flexible production.

New concepts are being developed to improve the operational management of the critical areas within the long rolling mill. Using existing installed technology combined with smart sensors like non-contact measurement devices, vision systems, intelligent temperature measurement, RFID for product tracking, all these devices will provide real time data with this information a higher level of automation can be achieved that will substantially improve:

Product Quality, Rolling process, Rolling Flexibility, Operating Costs, Maintenance costs, Operation set up, Operator Intervention in the rolling process and Product Storage and logistics.

This paper describes how the digitalization of the information collection and distribution will lead to a revolution in long rolling mill control systems. The benefits of adding intelligent sensors are highlighted because they are critical to enhancing the mills performance in all areas.

Hot Strip Mill / 79

New strip tension control for better thickness performance at finishing mills

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Rolling of thin strips in a finishing mill of Endless Strip Production (ESP), Compact Strip Production (CSP) and Hot Strip Mill (HSM) with an outstanding thickness performance and stability has increased requirements to the tension and thickness control concept of finishing mills. To fulfill these requirements Primetals Technologies developed in the first step a new control concept for rolling of very thin hot strips in a finishing mill of an ESP which is called "Ultra-Thin Rolling Control". This is an adapted control concept of Tandem Cold Mills, which has been used successfully many times during cold rolling.

The concept uses primary the roll gap to control the entry strip tension at the mill stand. Thereby the looper measures the strip tension between the stand while not changing its position. The controller is implemented at each mill stand. Depending on the material dimension or the rolling condition the controller mode will be selected accordingly and with smooth transition functionality.

This control improves at Rizhao ESP 3 the strip tension and - thickness performance during rolling in endless mode by using fast actuators and by compensating periodic disturbances. Moreover it is well adjusted to the Thickness Monitor, which controls the exit thickness of finishing mill.

In the next step Primetals Technologies works on an extension of "Ultra-Thin Rolling Control" for rolling of thin hot strips in a finishing mill of a CSP and of a HSM with an improved thickness performance and stability.

Industry 4.0 / 81

Valuable principles for effective planning & scheduling: A holistic approach

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The utilization of production facilities in an optimum way, with reliable due date fulfillment, reducing raw material and energy consumption, are challenges iron and steel companies are facing in their business every day.

By using an APS Advanced Planning and Scheduling System such goals can be achieved to increase the competitiveness of iron and steel producers.

A sophisticated APS supports the overall planning process by applying complex rules based on product and order mix, its production routings with corresponding processing and transport times and resource availability. Specific technological as well as steel grade and energy related constraints are also considered to meet company specific KPIs.

In general the task of APS is to support the preferred work-to-order concept, by assigning work-orders to available production facilities along the product specific process route and generate optimized material sequences for critical work centers. Orders describe the type and amount of products to be produced by a required due date in a specific production plant.

Secondary Metallurgy / 82**Steel vacuum degassing mechanical pumping system without process gas filter: latest technical developments for reduction in CAPEX and OPEX****Author(s):** Mr. MILOCCO, Mauro¹**Co-author(s):** Mr. TRIGATTI, Fabio¹ ; Mr. GOTTSCHLICH, Uwe² ; Mr. SIEBELS, Soenke²¹ SMS group SpA² Flowserve SIHI pumps**Corresponding Author(s):** vittoria.girola@sms-group.com

After years of meltshop trials, the final technical solution for a Mechanical Pumping System for Vacuum treatment in Steelmaking has been finalized by SMS group and the pump manufacturing company Flowserve/SiHi. The result of trials and validation processes of the technology are presented in this paper outlining the optimal solution for a series of installations for specific technical demands. Existing steam ejector revamping, small VTD, HI-dust production process such as VOD or VD-OB or RH-OB, limited space layouts and ATEX requirements are all challenges that are well answered by this innovative solution: a game changer and a technological step ahead.

Electric Arc Furnace / 83**Technical update on the SMS group automatic slag door condoor: lessons learned and results achieved in 7 years of experience****Author(s):** Mr. MILOCCO, Mauro¹**Co-author(s):** Mr. LANARI, Andrea¹ ; Mr. VOLPE, Marco¹ ; Mr. PORRACIN, Paolo¹¹ SMS group SpA**Corresponding Author(s):** vittoria.girola@sms-group.com

After 7 years and 14 installations worldwide of the Condoor (aka Texas Tailgate), the results achieved and the lessons learned leading to the present technical solution are presented, in 3 major steps summing up hundreds of technical improvements, each born from steelmaker experiences and requirements. Not all stories have been positive but each experience, especially when shared by the Supplier and the Final Users, meant a step ahead in the development of a product that guarantees enhanced Safety and a reduction of Operating Costs in different areas, as far as modern steelmaking is concerned.

Electric Arc Furnace / 84**EAF double probe extraction system for off-gas analysis: the SMS group's cornerstone for EAF process optimization solutions – The synergy program****Author(s):** Mr. LANARI, Andrea¹**Co-author(s):** Mr. MILOCCO, Mauro¹ ; Mr. TRIGATTI, Fabio¹¹ SMS group SpA**Corresponding Author(s):** vittoria.girola@sms-group.com

Modern EAFs require enhanced Safety and improved, consistent Performances; these features should be linked together, if possible. Both modern well-designed furnaces and more dated ones can benefit from the latest technology and equipment for removing operators from hazardous places, thus leaving dangerous activities to automated systems, while other technologies can read actual performances for the continuous optimization of the melting and refining phases in real time, together with precise process prediction. Off-gas analysis based on an extractive double

probe on the 4th hole is the cornerstone of this pack of solutions which SMS calls “Synergy” offered as modular packages with a proven reduction in OPEX.

Industry 4.0 / 85

Practical user experience with an Industrie 4.0 electrode control system

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Industrie 4.0 is slowly but surely arriving in the melt shops. Furnaces are being equipped with more and more sensors, digital models are increasing the degree of automation, and information is being shared between different aggregates within the plant.

Because the electrode control system plays a key role in electric steelmaking, it naturally assumes an important position in the melt shop’s Industrie 4.0 strategy. In addition to reliable, state-of-the-art core regulation functionality, monitoring and reporting tools and the ability to communicate with other equipment are also required. Therefore, the latest generation of our electrode control system, the Melt Expert, was developed based on Industrie 4.0 design principles.

Intelligent plant condition diagnostics, performance monitoring, and user-defined reporting are essential modules in this new system. With these functionalities, electrode control systems are developing into the information and control center of the furnace.

A newly developed software app brings most relevant process information to mobile devices. This feature allows steelmakers to keep an eye on the performance of their equipment anytime and anywhere.

This paper describes the new features of the electrode control system and shares our customers’ operational experience. Our focus is on the practical aspects of plant status monitoring, KPI reporting, and diagnostic functionality as well as the improvements achieved.

Cost & Process Control / 86

Off the beaten path: New condition monitoring applications in steel making

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For fast rotating equipment (bearings, pumps, motors, gears, etc) various condition monitoring techniques, predominantly vibration analysis, allow predictive maintenance practices to be applied. For slow rotating equipment (1 rpm) the situation is quite different. Our approach how to monitor such equipment is covered in the first part of the paper. Vibration monitoring is typically not possible, because there is not enough energy in the vibrations to be measured and analyzed, but shock pulse measurements allow for the first time to deliver accurate information about the condition of the equipment. The application of this technique for two examples of very slow rotating equipment is explained in detail. The first example is the ladle turret and the second is the BOF converter.

The second new approach for maintenance assistance is the Acoustic Expert System from Primetals Technologies. Recording and analysis of sounds produced by the equipment lead to a wide field of applications for asset but also for process monitoring. This 24/7 acoustic monitoring system enables a new way in condition based maintenance. Applications at environmental plants, steelmaking facilities, casting & rolling and material handling show the universal usability of the

described system. Using several example installations the method is described in detail. Achieved results are provided as well. An outlook about further applications concludes the paper.

Blast Furnace Ironmaking / 87

Holistic optimization models – recent developments in iron-making process control

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State-of-the-art process control systems are currently utilized with the intention to optimize the production process for certain individual aggregates (e.g. blast furnace, sinter plant, etc.) based on locally and temporally limited information. Following the spirit of Industry 4.0, the idea of holistic optimization models goes one step further by enhancing the performance of a plant through establishing a broader view on the available data. This goal is achieved with a detailed analysis of historical information and/or by connecting information from different aggregates. Primetals considers the holistic ironmaking optimization models as an important step towards the vision of a Smart Factory.

In this paper, we present the most recent developments from Primetals Technologies for the Level 2 systems for blast furnaces and sinter plants. Improved decision support and detailed process analysis are two points amongst many, which benefit from our holistic approach. We demonstrate with examples from recent installations how plant operators and process engineers can extract maximum value from the seamless integration of holistic optimization models into the Primetals proven process optimization solution.

Secondary Metallurgy / 89

Improvement of productivity for ultra-low carbon grade of Cr base ferrite stainless steel

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JFE Steel Corporation produces around 0.6 million tons of Cr base ferrite stainless steel per year at the Chiba Works. Recently, the demand of ultra-low carbon grade of Cr base ferrite stainless steel is increasing for using automotive exhaust system parts and so on. In the case of producing ultra-low carbon Cr base ferrite stainless steel, the bottle neck of the production line is Vacuum Oxygen Decarburization (VOD) process as secondary refining facility. In order to increase its productivity, we improve the method for decarburizing molten Cr base stainless steel by the following measures: (1) Optimizing the ratio of mixing oxygen and argon through the blowing top lance under vacuum to accelerate a decarburizing speed by reducing CO partial pressure and (2) Changing a materials-feeding process to keep higher temperature of molten Cr base stainless steel in VOD process than before. As a result, the decarburization time in the improved VOD process is reduced by 25% as compared with the conventional one and also the productivity is increased by 35%.

Industry 4.0 / 91

The digitalization of steel production

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State-of-the-art automation information technology and connectivity enables the digitalization of steel production that goes far beyond conventional automation of industrial production. Initiatives have been started around the globe to foster digitalization like IIoT (Industrial Internet of Things) in the US, Industry 4.0 in Germany or China2025. Primetals Technologies is actively driving the digitalization shaping the future of steel production.

Intelligent combination of sensor technology combined with digital models as well as quality and production planning and control systems leads to new dimensions in product quality and production cost reduction.

New diagnostic ways allow intuitive fault tracing or processing to support faster maintenance. Digital assistants support both operation and maintenance using context-oriented or self learned information.

Industry 4.0 / 92

Know-how based root-cause analysis tool to ensure high product quality and process stability

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The challenging and competitive market situation caused by worldwide excess capacity forces more and more steel producers into the market of high-quality, high-price products in order to increase their profits. Compared to commodity grades high-quality products pose substantial demands on the quality management, which has to address extremely tight production tolerances across the entire production chain and additional documentation activities in order to fulfill product and customer related quality standards. All these activities take advantage from adequate IT-system support and appropriately trained employees in order to operate and manage the plant within tight tolerances across the entire production route.

In order to support steel producers who want to improve product quality and production efficiency, Primetals has developed its TPQC (Through-Process Quality Control) system. TPQC is a know-how based through-process quality management and control system, which performs automated rule-based quality checks for the entire production route driven by Primetals' unique know-how based root-cause analysis features. The system provides product specific assistance for quality engineers and operators to help them identifying the causes of detected quality deviations. Due to the root-cause analysis quality engineers and operators are receiving detailed instructions regarding so called corrective actions, which are meant to eliminate the causes of non-conformities. Thus, TPQC actually is both, a quality system and a learning tool, aiming at quality and process sustainability, by application of supplemental technological know-how. The specific root-cause analysis feature is the result of a team work between Primetals IT and automation experts and Primetals' metallurgical technologists, contributing the required product and grade specific know-how.

New Ironmaking Technologies / 93

DR plant process optimization with DRIPax™ expert system

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An integrated process optimization system for MIDREX DR Plants has jointly been developed by Primetals Technologies and MIDREX Technologies. This system was installed for the first time at the MIDREX DR plant Module 2 of Qatar Steel. The new product quality prediction models achieve high prediction accuracy – hours before the measured data are available. This supports quick decision-making to keep quality targets and a stable DRI quality. Due to the improved control of the DRI quality, significant savings can be expected at the EAFs downstream. The DR Plant Expert System, a rule-based advisory system to assist panel operators in decision-making is the next step to further enhance the system. This expert system has been launched for the first time within the scope of the process optimization system installed at the new MIDREX DR Plant of voestalpine Texas LLC.

Electric Arc Furnace / 94

Extended new overview of chemical injection systems at the EAF

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This paper shows an overview on state of the art chemical injection systems at the EAF. Modern injection solutions, lower consumption costs, increased productivity and safety. These systems are easily upgradable to any EAF. Within a short shut down time, the installation of modern combined injection systems will lead to huge productivity and process improvements. The chemical injection portfolio of Primetals includes solutions for every type of process routes. The paper will consist of:

- History of chemical injection at the EAF
- Overview of state of the art injection systems for every type of electric arc furnaces
- Detailed description of the new RCB 3.0 system.
- Preview of the future RCB Move technology

Electric Arc Furnace / 96

Latest modernization developments for electric arc furnaces

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For Electric Arc Furnaces (EAF) high performance and productivity can be reached by fully utilized equipment and products and with the associated process knowhow for a mostly uniformed and safer operation.

The furnace components, also associated with supporting products have to be designed for a maximum power input, utilization and safe operation. Cycle times during power off and power on times may be reduced with a faster and safer process.

The latest modernization developments for Electric Arc Furnaces (EAF) allows to:

- Increase productivity
- Decrease conversion costs
- Operate with a symmetrical power input
- Limit refractory wear
- Improve plant availability and life time with heavy duty components
- Improved safe operation by utilization of automated systems

In this paper, the latest results of EAF Modernization by PRIMETALS Technologies GmbH will be shown and reported.

Long Products / 98

Forging-like rolling with high reduction of SBQ long products

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The Special Bar Quality family comprises a wide range of steel grades, mainly requested by the automotive, energy and engineering sectors, for applications where significant performances are required (eg. stresses, temperatures, working cycles, etc.). To meet these requirements it is necessary to reach a precise control of both the mechanical characteristics and metallurgy structures along the whole production chain. For semi-product with large dimensions, such as equivalent diameters around 300 mm, this is traditionally obtained through a manufacturing route which comprises the casting in ingots followed by reheating, forging and rolling. After 2010, new processes were investigated and technologies developed to replace the ingot route with a continuous casting followed by controlled high-reduction rolling. In these processes a seamless integration of CCM with rolling is implemented so to obtain the precise control of material flow, applied deformation and working temperatures. By using the proper combination of rolling diameter, speed and applied reduction, a very good control of the metallurgy structure across the whole section can be obtained, so to also remove the internal discontinuities ("voids") generated during the continuous casting. These processes, which can be defined "forging-like", are applicable to several grades also with large semi-product dimensions (300 mm and more). Besides, removing the ingot route means increased yield and productivity, which is very beneficial to the economical management of the plant. An example of this "forging-like" process is represented by the high-reduction blooming stand installed by Acciaierie Venete in the Padova-Camin mill. This article describes its main concepts as well as its technology and process features.

Long Products / 103

The production of railway rails in modern and efficient plants - The new ARBZ rail mill

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In the world, the rail production is on a growing trend as a consequence of the market interest to high-speed and heavy-haul transports. A confirmation to this come from the main international standards having been up-to-dated or re-issued after 2010, in USA, Europe, Russia, India and China.

In 2014, the rail production in the world was approximately 12 million tons (Mt), of which 8 were produced in plants commissioned after 2010. Head-hardened rails account for some 1.2 Mt, with its growth until 2025 expected to be in double-digit range.

Modern rolling mills for rails and sections must achieve high quality and productivity levels, so to obtain the required efficiency and flexibility for a cost-effective operation. The latest generation installations (eg. ARBZ in Kazakhstan) incorporate and integrate the most recent advances of process, equipment and control system. They consist of mechatronical systems which can consistently repeat the transformation processes, under the automated control of the production route. They present several advantages in terms of product quality, productivity, flexibility, energy and media consumption.

This article describes the main innovations introduced by Primetals Technologies for the production of rails, bringing as example the ARBZ section and rail mill in Kazakhstan.

Hot Strip Mill / 106

Development of looper shape meter in hot rolling

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Primetals Technologies Japan, Ltd. has developed the contact-type inline strip shape meter (Looper Shape Meter, hereinafter LSM) and has been marketing it for hot strip mills, where continuous inline strip shape measurement is long-awaited. The LSM consists of seven segmented rolls aligned in the width direction. Low hysteresis is obtained by applying torque meters at each segment. An internal water cooling system is employed and sufficient durability was confirmed. LSM has been operating for more than 8 years on an actual hot strip mill. This paper describes the development details of LSM.

Cold Rolling Mill / 107

Wear generation during cold strip rolling - a model based analysis

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In cold strip rolling, the amount of wear generated in the contact zone influences the surface quality of the final product, and, by influencing the coefficient of friction between work roll and strip, the force and power requirements of the mill. Most of this wear is expected to be generated from the strip, as the rolls are generally much harder.

In order to study the generation of wear during cold rolling and the impact of important influencing factors, a mathematical model for the prediction of wear extracted from the strip surface was developed. This model is an extension of the modular tribological cold rolling model developed by the authors [1]. The proposed modelling approach utilizes a locally distributed implementation

of the well-known Archard's equation [2] for the prediction of the generated strip wear volume. The wear coefficient in Archard's equation is determined by a fractional film defect model [3] reflecting the lubrication efficiency of the interface between work roll and strip.

The wear model for cold strip rolling was utilized for the prediction of strip wear generated in typical rolling schedules on a production mill. Based on these schedules, the influence of significant rolling parameters (e.g., strip material grade, thickness reduction) on the amount of generated strip wear was examined. Together with the results of the tribological cold rolling model, the interdependence between coefficient of friction and strip wear generated during cold rolling could be investigated.

The presented model significantly contributes to a better understanding of the interrelations between friction and wear in cold rolling. It allows for the prediction of strip wear generated in different stands of a rolling mill depending on rolling parameters, lubricant properties, and the rolled product. Furthermore, the presented simulation results allow systematic investigations on the influence of significant rolling parameters on the amount of strip wear generated in typical production mills.

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Hot Strip Mill / 108

Mill stabilizing device for reduction of mill vibration in hot rolling

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Pair Cross mill (hereinafter PC mill) was developed widely to control the shape and crown of rolled strips for high productivity and saving energy. Recently, the demand for harder and thinner hot rolled strip, such as high strength steel or dual phase type high strength steel, has been increasing. In such production for harder and thinner hot rolled strip, higher reductions and larger rolling forces are required on the finishing mill stands. With the increase in rolling forces, in reduction and in rolling speed, the impact forces during the threading of the strip head end increase and mill vibrations can start to occur. The larger impact force or mill vibration causes not only the reduction of life time of the mechanical parts but also reduction of operational stability and productivity. In order to counter these effects, Mill Stabilizing Device, which consists of hydraulic cylinders equipped with damping orifices, was developed and applied for PC mill. This paper will present the PC mill equipped with Mill Stabilizing Device technology and the results of reduction of mill vibration and impact forces in an actual production line.

Electric Arc Furnace / 110

SHARC - Shaft arc furnace - Minimized energy consumption, efficient scrap preheating and low conversion costs

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Steelmakers strive for a high degree of effectiveness combined with efficient energy. Equally important are productivity of the process and the quality of the product.

Hellenic Halyvourgia, Greece (HLV) and SMS group have developed a completely new and unique process for scrap preheating: the SHARC furnace (shaft arc furnace) process. This process minimizes energy consumption to a minimum level and simultaneously generates a significant increase in economic efficiency. Modern automation systems and environmental technologies comply with the strict requirements on occupational health and safety and environmental protection. The SHARC at HLV is a 100 ton and 54 MW direct-current electric arc furnace with preheating shafts in which the scrap is dried and preheated. With the SHARC furnace, it is possible to ensure economically efficient and smooth operation even when charging low-quality scrap (low density) without additional pretreatment. This design is unique worldwide and has the advantage that the scrap is melted homogeneously.

The SHARC has been operating successfully and reliably in Greece. The cooperation between HLV and SMS mainly focuses on the further technological development and marketing of the furnace.

Hot Plate Mill / 111

Recent applications of the MULPIC® plate cooling technology

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The current market is seeing an increase in the demand of added value products including the production of high strength plates which ideally must keep the use of high cost alloys to a minimum. Applications such as oil and gas pipelines, offshore structures and shipbuilding, require good control of both mechanical properties and the final shape of the plates. The production of such plate is more economically possible with the application of the MULPIC plate cooling technology coupled with advanced process control.

This paper describes a recent modernization project at the plate line at China Steel's Kaohsiung Works, with the aim of increasing the product mix and improving the quality of cooled products. China Steel and Primetals Technology worked closely together to install the MULPIC upstream of the current laminar cooling machine to allow higher cooling rates to be achieved by using the Direct Quench cooling technology. The modular design philosophy used in the MULPIC reduced installation time and Final Acceptance was achieved with all guarantees passed.

An overview of this project is presented together with a description of the cooling system and its associated automation. The MULPIC is designed to provide the high cooling rates and temperature accuracy needed to achieve the combination of high strength and toughness essential to plates destined for demanding applications. Plate flatness accuracy is controlled using edge masking, crown valves and head tail masking.

This paper also demonstrates the importance of the advanced model based automation coupled with a sophisticated adaptation. The new Primetals valve technology is also described which allows the flow to be controlled to the accuracy needed for precise plate cooling. Typical performance results are given which demonstrate the accuracy that was achieved.

Secondary Metallurgy / 112

Vacuum converter – Producing special steels and ferroalloys

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The SMS group vacuum converter technology combines the advantages of the AOD converter and the VOD technologies. In the vacuum converter process, the final decarburization step of stainless steel grades and ferroalloys takes place under vacuum. The dilution of oxygen by inert gases known from the AOD process is largely omitted.

Use of SMS group's vacuum converter technology ensures the reproducible achievement of ultra-low carbon, nitrogen, and hydrogen contents in the production of stainless steel. The product portfolio for high-chromium steel grades can be expanded accordingly.

For stainless, acid- and heat-resistant steel grades requiring low final carbon and nitrogen contents, the production costs are significantly reduced mainly by lower consumptions of argon and reduction material. The process time can be strongly shortened compared to standard AOD operation.

The vacuum converter technology is also suitable for production of duplex steel grades with high nitrogen contents. Following the decarburization down to lowest carbon contents under vacuum the nitrification process is carried out under atmospheric conditions in the converter. Applying much higher nitrogen blowing rates by bottom tuyères compared to typical lancing used in secondary ladle metallurgy the process time can be largely reduced.

SMS group's vacuum converter technology stands for cost effective production of medium and low carbon ferroalloys. Due to refining under vacuum conditions even the production of low carbon FeCr is possible in the converter.

Depending on the target carbon contents expensive argon is partly or fully replaced with CO₂. In the chemical industries, many processes generate carbon dioxide as a waste product, explaining the low price of the gas in comparison to argon. The entire process engineering ensures lowest operating costs.

Used as a reaction gas, CO₂ has a strong cooling effect in decarburization. The addition of costly solid metallic coolants can be significantly reduced when treating ferrochrome and ferromanganese leading to higher productivity as well as reduced processing costs.

The presentation introduces the vacuum converter technology and its benefits.

Cost & Process Control / 113

Optimizing OPEX for steel plants – Improve process control and energy efficiency

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In a competitive environment, innovative products which need very minimal investments can help in improving OPEX and thereby helping staying competitive. This paper presents some of such innovative products which SMS group has developed by focusing on energy costs, asset utilization, productivity and material costs.

X Pact® FEOS X Pact® FEOS is a furnace energy optimization system for EAFs. It consists of various modules which help operator in [U+FOA1] tracking the thermal state of the furnace and accordingly control the tap positions for the transformers, [U+FOA1] starting the carbon injection at an optimal foaming slag, [U+FOA1] control the amount of injection material and [U+FOA1] taking a holistic view of energy requirements of the furnace and optimizing it. By this, X Pact® FEOS reduces energy and material costs and additionally improves productivity.

X Pact® Gas Cleaning Assist The X-Pact® Gas Cleaning Assist enables precise control of the volume flows at every emission point and reduces pressure loss of the whole system by considering the process stage at every emission point. It uses a robust mathematical algorithm which takes into account the actual duct layout and construction. By this, X Pact® Gas Cleaning Assist reduces energy costs while fulfilling environmental requirements.

X Pact® Gas Cleaning Control Basic Oxygen Furnaces equipped with wet gas cleaning systems, suction is enabled by an induced draft fan which runs at constant speed during the oxygen blowing

period. The X Pact® Gas Cleaning Control uses feedback from the total process like oxygen flow rate, opening at the converter mouths and material feed-rates to set the ID fan speed at its most efficient point and then for fine control the Venturi throat is adjusted. The X-Pact® Gas Cleaning Control ensures that energy saving is there while cleaning efficiency of the gas is maintained.

X Pact® AutoTapping The use of X-Pact® AutoTapping in Basic Oxygen Furnaces results in optimized and consistent tapping conditions irrespective of current age of the lining. It also saves time and increase productivity of the tapping operators.

X Pact® Ladle Management The X Pact® Ladle Management helps to reduce the refractory costs, preheating fuel costs and related labor costs. The thermal loss calculation saves [U+FOA1] cost of extra heating in ladle furnace [U+FOA1] additional process delays (incurred in delivering steel at right temperature to downstream unit), [U+FOA1] metallurgical disadvantages of receiving steel at caster at too low or too high temperature and [U+FOA1] occasional costs of ladle breakout due to inability to judge the residual life of the ladle.

X Pact® Laser Off-Gas The In-situ X Pact® Laser Off-Gas reduces the maintenance requirements of the traditional extractive type of gas analyzers which are typically used and increase reliability of this instrument.

AE-Reg Advanced Electrode Regulator Customer Benefits : - less energy consumption(4,0%) - shorter power-on time - less electrode breakages - less carbon for EAF slag foaming practice
Synergy Charge – Advanced Process Control for the Scrap Yard - Real time position tracking of scrap yard cranes and cars - Tracking & recording of each single Scrap pick movement - Business Intelligence Tool to analyse scrap yard efficiency
Conyard – Advanced Yard management - Mobile access via tablets - 3D presentation of products present in the storage yard - Seamless integration with upstream areas

Rolling / 114

i Box pickling tanks for production improvement of advanced high strength steel upgraded from deep bath tank

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For demands of production increasing of advanced high strength steel (hereinafter AHSS), steel manufacturers face short production capacity of pickling line. Primetals Technologies Japan, Ltd (herein after PTJ) have proposed *i* Box pickling tank to improve production capacity, which is most advanced, maintenance easy and saving energy. Since *i* Box pickling tank need storage tanks of acid solution to reduce over pickling at line stop, wider space for them is required. To reduce the necessary space, PTJ propose new and unique designed configuration system of *i* Box pickling tank to revamp from Deep bath tank.

Key words: *i* Box pickling tank, Deep Bath Tank, Advanced High Strength steel, Pickling Speed, Storage tank

Cold Rolling Mill / 115

Latest PL-TCM technologies for advanced high strength steel applications

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Safety and environmental considerations have significantly increased the demand for Advanced High Strength Steels for automotive applications. Primetals Technologies has incorporated various advanced technologies in the latest supplied Continuous Pickle Line coupled with Tandem Cold Mills (PL-TCM) to satisfy the increased process demands to produce these harder and thinner steels, achieve the faster rolling speeds required to meet today's production targets, and provide cost effective solutions in an extremely competitive market environment. This paper will introduce some of these advanced technologies, including highly efficient iBox Pickling Technology with polypropylene tanks, the 6-High Universal Crown Control Mill (UCM-Mill) with unmatched shape control capability, the Hyper-UCM Mill for stable rolling of Ultra High Strength Steels, and the Flying Width Change (FWC) Side Trimmer for continuous trimming operation. The advantages of these technologies to produce these difficult steel grades will be discussed, as well as the implementation of these technologies in new installations or modernizations of existing facilities to maintain high availability of the production equipment.

Cold Rolling Mill / 116

Newly developed universal crown control mill “HYPER UCM” for rolling of high-hardness and thinner steel

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The increasing demand of ever higher hardness and thinner steel, for example “advanced high strength steel” in the automotive industry, “tin plate” and “electrical (silicon) steel”, has accelerated in recent years. Particularly in the cold rolling field, harder- and thinner-strip rolling techniques have become urgent requirements which must be dealt with. The HYPER UC-MILL, which was newly developed for rolling harder- and thinner-strips with a higher accuracy, provides a high degree of strip quality by the use of smaller work roll diameter driven by work roll drive system using high-stiffness special spindles developed by Primetals Technologies. HYPER UC-MILL is the most advanced 6-High UCM (Universal Crown control Mill) which has optimal combination of work roll diameter, intermediate roll diameter and back up roll diameter in consideration of strip shape control ability and Hertz stress between rolls. As a result, HYPER UC-MILL has achieved 20-40% smaller work rolls compared with conventional UCMS' under the work roll drive system. One of key-technologies that realized HYPER UC-MILL is high-performance work roll drive system consisting of special gear reducer and special spindles. To drive smaller work roll, gear reducers and spindles have designed to keep sufficiently rigidity and stability under the condition of high revolution. In this paper, Primetals Technologies will highlight the basic configuration, performance and supply references of HYPER UC-MILL in the tandem mill and reversing mill.

Surface Technologies / 117

Hot flat product surface inspection - Latest developments

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Surface quality monitoring is primarily implemented in the last steps of steel manufacturing before shipment to the end user. However, an increasing trend for also addressing this topic in the upstream stages, such as hot rolling plant, is tackled by Primetals Technologies to give steel producers the key to a global optimized yield management, and efficient “lessons learned” processes.

After the last developments of SIAS Next Gen platform, including High Resolution and Near Infra-Red, some site results will be exposed on the very specific high constraints lines such as ESP

Endless Strip Production and Plate Mills, and highlights the related most interesting aspects for our customers.

Cold Rolling Mill / 118

Industrial results obtained with the new generation of laser welder

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Primetals Technologies has made an important Research & Development effort on laser welder field. The last step of its program was the evolution of its laser welder range by implementing the Solid state technology with laser cutting and welding.

Since this step, twelve welders have been manufactured by Primetals Technologies. After more than six years of industrial feedback, the results are showing a high level of performance and reliability on process with a product weldability from Silicon steel to High Strength Steel with DP and TRIP grades and a constant cutting and welding quality. The operation enables a high reliability and optimized operator control, an optimum weld quality and geometry control and a perfect strip centering. Maintenance has also benefited from this technological evolution with a low maintenance level thanks to the use of optic fiber and Asolid Laser source and a preventive maintenance with the integrated Control Monitoring System.

Some industrial results obtained in continuous processing lines recently installed in China will be exposed and highlights the related most interesting aspects for our customers.

Cold Rolling Mill / 120

Introduction of cold rolling complex for tin plate

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Demands for cold rolled tin-plated or galvanized steel sheet products are increasing rapidly in Turkey supported by its economic expansion. A cold rolling complex project for Tosyali-Toyo Celik Anonim Sirketi has now started in Turkey to meet the demands. Primetals Technologies supplies PL-TCM, Tin-CAL and 2-std. Temper DCR Mill for the complex. This paper will introduce the latest technologies applied to those facilities for producing tin-plated steel sheets including high-efficiency and energy saving i Box pickling process for PL-TCM, 6-High UCM-Mills for PL-TCM and Temper DCR Mill, and high-speed steady operation by vertical furnace with tension leveler for CAL.

Cold Rolling Mill / 121

Development of advanced 20Hi split housing ZR-mill (HZ-mill) for stainless and electrical steel

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As a technology for heavy reduction cold rolling of hard materials such as stainless steel and electrical steel, the Advanced 20Hi Split Housing ZR-Mill (HZ-Mill) has been developed as a 20Hi Cluster mill with a split inner housing, replacing the conventional large-scale mono-block type 20Hi ZRM. In the HZ-Mill, workability can be improved by increasing a roll clearance between the work rolls, and the structure has been optimized to sufficiently secure the required rigidity. In addition, this mill is equipped with a high response hydraulic screw-down system and Double AS-U mechanism, thereby expanding functions of thickness and shape control.

Hot Strip Mill / 122

A pioneering HSM side guide system eliminating strip defects at tremendously extended service life

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In the field of down coiler technology in hot strip mills PRIMETALS Technologies has developed new innovative products which remove a head-ache by substantially simplifying operation and maintenance work and considerably reducing operation and maintenance costs.

Contrary to conventional wear plates where the passing strip always cuts into the plates along the same line, wear on Primetals' Eco Slide Discs is distributed across the entire disc surface. This avoids strip edge defects and extends the service life from few days using conventional wear plates to several weeks without any service requirement. Another great feature of the Eco Slide Discs is their inherent self-cleaning effect, which reduces the risk of material deposits falling onto the strip, hence eliminating an important cause of hot strip surface damages.

Oxygen Steelmaking / 125

Dynamic on-line monitoring and end point control of dephosphorisation in the BOF converter

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Treatment of hot metal in a Basic Oxygen Furnace (BOF) is a highly exothermic, complex, oxidising-refining process in order to remove hot metal impurities (mainly carbon and phosphorus) from iron and to achieve an optimal end temperature for further treatment of the crude steel. End-point control of the BOF process is in general based on static charge calculations and observation of decarburisation via off-gas analysis or in-blow substance measurements of steel temperature and carbon content. On-line information on dephosphorisation behaviour is not available.

The objective of the research project BOFdePhos, funded by the European RFCS programme, is the development of a comprehensive dynamic model for on-line monitoring and control of the BOF process behaviour with focus on dephosphorisation.

For that purpose extensive investigations on thermodynamics and kinetics regarding the main aspects of dephosphorisation were made. This includes the development of a thermodynamic database covering the dephosphorisation reaction, as well as the performance of various laboratory experiments revealing valuable information about the main contact area for dephosphorisation reactions (e.g. slag foam structure, slag viscosity, droplets behaviour in the foam) and the rate of lime dissolution in slag.

The results of these investigations, together with the results of CFD model calculations of flow fields and mixing behaviour in steel and slag, defined the basis for set-up of multi-zone reaction models which were used for detailed simulations of the dephosphorisation process in the BOF converter in order to derive appropriate submodels to be applied within on-line process models. Necessary BOF process data for validation of the model calculations were provided from the Tata Steel converters in Port Talbot and IJmuiden.

Furthermore, a new sensor technology measuring the oxygen activity in the slag as well as the slag height and bath level and allowing also for in-situ slag samplings has been developed and successfully tested within this project. These new measurements provide additional information to the enhanced on-line models for an optimised dynamic end-point control of the BOF process.

Blast Furnace Ironmaking / 126

Analysis of copper stave breakage and restoration technology in Pohang no.4 Blast Furnace

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An early breakage of the copper stave cooling pipe is a serious issue in ironmaking worldwide. This breakage of the copper stave caused unstable operation and shortened service life. Pohang No.4 BF experienced a leakage of coolant into the furnace caused by rapid wear of copper stave. It was found that the main causes of the breakage are high productivity operation ever since blow-in and blast furnace design.

Pohang No.4 BF installed ultrasonic sensor which can measure thickness of the worn copper stave before blow-in. Utilizing this accumulated thickness data we found out the existence of critical productivity which increased wear rate of copper stave dramatically.

In order to recover initial cooling capacity of copper stave, the method of stave replacement was applied first to the company. The copper staves in the sections S2, S1 and belly were quickly and successfully replaced in sequence. After the replacement of copper stave, No.4 BF restored normal operation condition and prolonged service life.

Cold Rolling Mill / 127

Stainless steel endless continuous cold rolling with X-HI® stands technology

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First successful flying roll change installation for increased production yield

Pushing the horizon of stainless steel continuous cold rolling mill performance on the edge of perfect strip quality level, not compromising with the highest yield and productivity ratios, has been given a new milestone by Primetals Technologies.

After a first reference of X-HI® technology tandem mill on the Direct Rolling Annealing and Pickling Line (DRAPL) of Baosteel Desheng, Primetals Technologies installed a later reference at Beihai Chengde on a Continuous Tandem Cold Mill (CTCM).

X-HI® technology has been especially designed to allow flexible and fully continuous rolling operation on 18-Hi mill type, with specific patents applied for endless rolling capability. Amongst differentiating features of X-HI® technology, the specific design and control of rolls position and efforts are giving the stability and precision required for ultimately extending the current rolling capabilities of such continuous stainless rolling mills.

This last commissioned reference is a continuous 5 stand tandem mill, equipped with mill entry and exit strip loopers allowing for no-stop rolling operation. This configuration increases significantly the mill yield ratio by limiting out-of-tolerance strip thickness and the productivity as well, thanks to endless continuous rolling operation. The concept draws innovative approach to allow fully automatic roll change operation with the strip passing through the said mill stand. As ultimate benefit for saving several minutes of production and eliminating off-gauge material, work roll change can be done on the fly without stopping the strip rolling process: while the roll gap is open, the thickness reduction at that stand is taken over by another actively rolling stand. Typical case shows work roll change operation achieved up to 120 m/min rolling speed. This operation can be done for all the rolls: WR, IMR and SSR, excepted BUR. This mode of operation is a world premiere and opens the field of new gains in the world of stainless steel and very high strength steel grades.

Blast Furnace Ironmaking / 128

Improvement of overall blast furnace performance after the revamping of the top charging system at ArcelorMittal Atlantique et Lorraine BF-2

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ArcelorMittal Atlantique et Lorraine BF-2 5th campaign started in 1992 was concluded in 2015 with a total hot metal production of 26 million tons. The furnace was stopped for 129 days, from August to December 2015 for a relining aiming to revamp the top charging system, the hearth, the casting house and the gas cleaning.

In terms of top charging system, existing Bell-top with movable armor has been replaced by a compact version of Paul Wurth's Bell-Less Top®. After the start-up, the operational performance of the blast furnace has been improved, notably the daily productivity, total equivalent coke rate and hot metal quality.

During the project, the plant and R&D teams worked together in different steps, from the choice of the best option in terms of design, up to the calibration of the main settings of the system, in order to optimize the charging parameters. Such a close cooperation between the industrial site and the R&D was very important for the project success.

This paper aims to describe the different steps of the revamping and to show how a more efficient control of the burden distribution is essential to improve the operational indicators.

Cokemaking / 131**Influence of kind and particle size of semi-soft coking coals on dilatation of blended coal****Author(s):** Ms. KONNO, Saori¹**Co-author(s):** Dr. KUBOTA, Yukihiko¹ ; Mr. UEBO, Kazuya² ; Dr. NOMURA, Seiji¹ ; Dr. ARIMA, Takashi³¹ *Nippon Steel & Sumitomo Metal Corporation*² *Nippon Steel & Sumitomo metal Corporation*³ *NIPPON STEEL & SUMIKIN TECHNOLOGY Corporation***Corresponding Author(s):** konno.cb4.saori@jp.nssmc.com

Recently, in an environment in which the fluctuations of coking coal price increase, in order to produce high strength coke at a low production cost, it is required that the blending technology applied to various kinds of coal. The dilatation of coal is one of the significant factors determining coke strength. It is known that in the case of blended coal that contains semi-soft coking coals, the dilatation value of blended coals does not agree with the weighted average value of coking coal and semi-soft coking coal, and it shows lower than the weighted average value. In this study, for the purpose of developing of the coal blending technology applied to various kinds of semi-soft coal, we investigated the inhibitory influence of kind and particle size of semi-soft coking coals on the dilatation of hard coking coal. In consequence, when the dilatation value of semi-soft coking coal is extremely low, the inhibitory influence on the dilatation of hard coking coal becomes high. As the particle size of low dilatation semi-soft coking coal becomes finer, it becomes higher. Moreover, we have clarified that the inhibitory influence on the dilatation of hard coking coal is dominated by the pore structure of semi-coke derived from semi-soft coking coals.

Long Products / 132**Modernization of the Kroman wire rod mill to increase productivity, utilization and product quality****Author(s):** Mr. KREJDOVSKY, Wade¹**Co-author(s):** Mr. KIEFER, Bruce¹¹ *Primetals Technologies USA LLC***Corresponding Author(s):** georg.krempl@primetals.com

A modernization project was undertaken by Kroman Celik Sanayii A.S. in order to improve their product quality, consistency and shape of the coil package, reduce maintenance and delays in rod mill, thereby increasing utilization and productivity. The project involved installation of a new Morgan Intelligent Pinch Roll and High Speed Laying Head, modifications to the existing controlled cooling conveyor, plus replacing the coil reforming station. The new pinch roll and laying head were to provide better control of the ring formation and consistency of the coil on the conveyor, while reducing delays on the conveyor. Changes to the controlled cooling conveyor included installation of new nozzle decks and Optimesh air distribution system along with re-arrangement of existing fans in order to improve both cooling rates and uniformity of cooling.

This paper explains details and features of the newly-installed equipment technology. Resulting product and process improvements are presented, including increased tensile strength and uniformity, reduction in delays on the conveyor and reform tub, plus improvements in coil quality.

Long Products / 135**Dynamic cooling control system of high strength steel wire rod****Author(s):** Mr. YU, Shih-Chuan¹**Co-author(s):** Mr. LIN, Yi-Ying¹ ; Mr. CHANG, Chen-Yang¹

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Mechanical properties of steel wire rod are mainly influence by chemical composition and cooling rate of Morgan Stelmor cooling system, especially for high strength wire rod. Since the chemical composition will slightly fluctuate among different heats, it will accordingly cause the variation of mechanical properties. Although it can be compensated by cooling process adjustment manually, this requires high attention and human effort. Moreover, the changing of environmental temperature means the heat capacity variation of cooling agent, which can influence the mechanical properties. Especially in subtropical regions, the ambient temperature difference between summer and winter can reach 25 [U+2103], the variation of ambient temperature can influence the mechanical properties greatly. This study is to develop for dynamic cooling control model to obtain more uniform tensile strength of high strength steel wire rod. The method is to establish a mechanical properties prediction model of high carbon wire rod by big data analysis. The first step is to implement the relation between chemical composition, environment temperature and tensile strength by statistic method. Next step is to implant the dynamic control application in current production coordinating system, which can check the chemical composition and environmental temperature before production, then adjust the production process automatically to minimize the variation of mechanical properties. After the test production, the tensile strength is more stable and harmful microstructures like coarse pearlite, martensite are reduced or even eliminated. From the results of test production, the dynamic cooling control system is confirmed to be capable of reducing the variation of mechanical properties and microstructure effectively. Furthermore, this system can automatically modify the cooling practice by monitoring the chemical composition and environmental temperature. The benefits of this system are reducing the manual operation effort, reducing the variation of product mechanical properties, thus promoting product competitiveness and realizing the vision of intelligent manufacturing.

Industry 4.0 / 136

The KPI-driven and agile metals supply chain

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Evolving market conditions in today's world – increased variability, volatility and complexity – require more agility than ever for metals supply chains. The bottom line is that future supply chain ROI maximization will not so much be driven by unit cost minimization but by the promotion and protection of flow of materials and information. This implies revisiting today's MRP and ERP systems by introducing new “pull oriented” planning concepts and new KPIs/metrics to measure flow performance. In particular, De-mand Driven MPR (DDMRP) is an emerging innovative approach using a multi-echelon “Po-sition, Protect, and Pull” methodology, to plan and manage decoupling inventory buffers.

Additionally, the “Industry 4.0” revolution will drive metals producers and their extended supply chain partners towards increased collaboration and transparency and towards harnessing new digital devices and software platforms to take advantage of Big Data opportunities. The key advantages that the Industrial Internet can bring to foster supply chain agility and flow are:

- Real time information on key intelligent ‘objects’ (e.g. a stock buffer)
- End-to-end visibility throughout the value chain network through seamless collection and distribution of supply chain data/events

Concretely, any software platform supporting planning and shop floor decisions should include a real time, online cockpit, displaying relevant KPI updates and prioritizing human actions to be taken in order to minimize supply chain flow disruptions. It should also support fast benchmarking of “what if” simulations.

This paper describes the steps taken by PSI Metals towards this new supply chain paradigm:

- A DDMRP slab replenishment study made at PSI Metals customer, demonstrating potential for substantial WIP savings

- The PSImetals Tuning Dashboard, allowing for KPI-driven planning optimization
- The KPI Assessment methodology, helping steel plant managers in defining the “right” KPIs and providing insight into conflicting objectives

Hot Plate Mill / 137

Product driven project methodology put into practice – how to implement a production management system for a plate mill line within 6 months

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Besides modern equipment and sophisticated process automation systems effective steel production requires a production management system which is coordinating the production processes on the shop floor and integrating those with the commercial processes. Implementation time has direct influence on the return of investment of such a system.

The product driven project methodology, a new project execution approach developed by PSI, recently lead to a successful implementation of a complex production management system for a Plate Mill line within six months. The project combined functionality in the areas of planning, production tracking, yard logistics and quality management into one integrated system, which was itself again seamlessly incorporated into the customer’s IT landscape of a newly introduced SAP system, an existing upstream raw material provision and a greenfield Plate Mill line. The production management system comprises a series of equipment and resources, including a slab yard, reheating furnaces, descaling, rolling mill, forced cooling, levelers, cooling beds, shear lines, flame cutting and semi-finished/finished product yards.

Some factors have been observed to be important for the success of the project, such as:

- The implementation team had expertise on customer processes
- Experts provided directly at the beginning of the project a training on the PSImetals Standard System, to then limit the following specification phase to a mere Fit Gap analysis.
- The external interfaces were either directly based on existing PSImetals Standard Interfaces or closely aligned to these interfaces
- The project was split into smaller deliveries, by this making the progress transparent on all sides, allowing very early interface testing and agile reaction on necessary changes
- We have used a mature and flexible product, developed over many years to serve as a standard to the metals industry

This paper describes the key success factors, the lessons learned and the benefits for the customer. It also provides a guideline for future projects in the field of metals production.

Industry 4.0 / 139

Custom fitted order dressing for metals industries

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Modeling Metals production becomes more challenging due to the constant increase of diversification on one hand and higher quality requirements on the other. At the same time globalization

drives the metals industries towards modern ERP “standards” that by default are designed for assembly production. All attempts to model metals production by BoMs are failing as soon as the constantly increasing number of materials let the maintenance effort explode. A costly integration of the well-known Excel sheets or homemade solutions does not seem to be a solution neither. Metals production requires tools that can model production dynamically and respect flow processes.

- Rule based calculation instead of “hard coded” BoMs and routings
- Dynamic recalculation on demand instead of maintaining hundreds of list
- Designed for product engineers not for IT specialist
- Full Support of the complex Quality requirements, Testing and Sampling logic instead of inspection plans designed for assembling production
- Considering variants and alternatives instead of linear Excel approaches

A team of experts in metals production together with mathematicians and IT specialists developed a production modeling tool that allows custom fitted order dressing for metals industries. This approach can be attached to MES and or ERP systems and supports a global and centralized ERP approach but takes the complexity of modeling flow production by using tools designed for assembly production. The order dressing tool has already successfully been introduced at different metals producers with various products (e.g. tubes, heavy plates, aluminum foil) around the world. The full flexibility can be illustrated on the one hand by the fact that the tool can be fed by any type of orders including pre-elaborated Production Orders, customer requirements or ERP Materials and the output would be complete Production Orders ready to be produced, offers including price and costs, usable ERP Materials or Master Data for the ERP system. On the other hand order dressing is capable to handle all kinds of metals specific production processes (ferrous and non-ferrous). The result can be evaluated by planning tools created by teams with the same expertise to run what if scenarios to better estimate the business impact. This paper shows the benefits of the aforementioned approach from a theoretical point of view as well as selected case studies.

Cold Rolling Mill / 140

Chatter management today at cold rolling mills. Theoretical background, integration into Genius CM condition monitoring, link to plant automation

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Chatter is one of the most crucial phenomenons in strip rolling, especially in the very fast operating process steps like cold rolling. Bringing mills to the maximum of their operational possibilities without entering the “chatter” areas is not only a challenging task for all producers of Aluminum and Steel strip and sheet but must also be supported comprehensively by the plant manufacturers. This paper gives an overview of the theoretical background of chatter phenomenons, components of an effective chatter management including the details of the new Genius CM analysis “Chatter Plus”, the challenges to provide a system offering multiple possibilities to analyze the related data. Additionally the Chatter Plus analysis results are actively used within the into Plant plant’s Electric & Automation system to avoid chatter marks and strip breakages.

Rolling / 141

Measurements of contact, friction and heat transfer during rolling

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The target of this work has been to in detail measure the conditions inside the roll gap during hot and cold rolling. For this purpose rolling was done using an instrumented work roll. The purpose was to measure contact length, contact force distribution, friction coefficient and heat transfer coefficient. The work roll used three contact sensors, two for measuring the contact loads and one for the measurement of the heat transfer inside the roll gap during rolling. One of the sensors is the “Rollsurf” sensor designed to minimise the penetration of material during rolling. The signals were transferred wirelessly. The measured contact length became larger than the contact length calculated using the most commonly used theoretical estimations. A better agreement is obtained if the elastic springback of the strip is regarded. The contact force distribution varies for different types of passes early, mid and late passes. For early passes the peak pressure is close to the entry side and for late passes the pressure peak is close to the exit side. This tendency is considerably weakened if the work roll is idle. A friction coefficient is calculated using the ratio of the measured tangential and the normal force. The result indicates that the friction coefficient strongly varies through the roll gap having high values at entry and exit and low values in between. The measurement of contact temperatures and calculation of HTC reveals that the heat transfer is strongly affected by the pass conditions. The measurements have provided information that will help to better understand the complex relationships inside the roll gap. This knowledge can be used for improving basic rolling models for friction and wear as well as models for heat transfer in the roll gap.

Secondary Metallurgy / 142

Development of high quality grades production techniques using a VOD plant at voestalpine Giesserei Linz

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The steel market is experiencing a difficult conjuncture: on the one hand steel producers minimize their investments while optimizing their over- production, on the other hand suppliers reduce their internal human resources and capacity in order to overcome the instability of the new era. A return to the steel production levels of the past is not expected in the short term. Research, development and plant concept optimization is one recipe to drive the future of the steel business. This article describes a new concept for a VOD plant developed as a result of thorough investigation and assessment of all possible solutions. A joint and tight cooperation with the final customer was necessary to reaching important results. This article consists of the contributions from the plant suppliers in terms of their experience and feedback, as well as the final user's. The final customer, voestalpine Giesserei Linz GmbH, and the plant supplier, Primetals Technologies, are both worldwide players and highly focused on reaching best quality and innovation. The article describes in detail a project that marks a change in the use of vacuum technologies for tank degassers.

Electric Arc Furnace / 143

Adaptation of CRM EAF model for 100% DRI charging and implementation at Lazaro-Cardenas plant

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During the last years CRM has developed a dynamic on/off-line model for the EAF process. Contrary to calculations using statistical inputs, CRM model uses a fundamental set of calculations based on thermodynamics and kinetics that takes dynamically into account furnace operating data. The purpose of the on-line application is to provide the operator with a better estimation of the melting state of the furnace and liquid steel temperatures to reduce the frequency of temperature measurements and increase the reliability of those taken. This in turn will enable lower tap temperatures and reduce energy consumption. The objective of the work presented in this paper is to apply the CRM EAF dynamic model for the first time to a DRI melting furnace. At this aim, new knowledge on DRI melting and modelling has been acquired. The CRM on-line EAF model was implemented at the four EAFs of Lazaro Cardenas (Mexico) plant operating with continuous feeding of DRI to improve monitoring of the process for carbon, temperature, and heat weight and to allow optimization. Thanks to the model implementation, the process control was improved and substantial gains have been observed on the number of sampling (one less per heat) and in the tapping temperature control (in average 3°C lower) resulting in a decrease of energy consumption (2kWh per heat).

Rolling / 145

Development of new mash seam welder (Cross Seam Welder, CSW) for carbon steel pickling line

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Primetals Technologies had developed a new mash seam welder (Cross Seam Welder, CSW) based on MSW features including low cost and compactness, enhancing its compatibility with Continuous Rolling of Steel Sheets at Thicknesses up to 6.5 mm.

The first order and second order for the CSW were received from JFE Steel Corporation, where they were installed in the Continuous Pickling Line. These revamping projects were to change the Welder from the flash butt welder (FBW) to the CSW. Additionally, the black scale remover was also developed and installed for use in pickling lines that enables welding by the CSW after the removal of the black scale on the surface of the coils as the first time in the world.

Key words: New Mash Seam Welder, Cross swaging, Weld step, Black scale remover, Pickling line

Gas Cleaning / 146

Enhancement of the EAF dust recycling in self-reducing briquettes by controlling their hydration behaviour

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The steel production via the EAF route produces free lime containing dust. In the case of carbon steel production, the main dust recycling process is the Waelz furnace, allowing the recovery of zinc but not of Fe. In the case of stainless steel production, the recovery of valuable alloying elements (a.o. nickel, chromium, and molybdenum) can be achieved by recycling the dust in the form of self-reducing briquettes into a liquid steel bath. A hydration step is mandatory before the briquetting of free lime bearing dust in order to avoid swelling and degradation of the produced briquettes.

The amount of added water must be well controlled in order to ensure the full hydration and also to limit the residual humidity to avoid the need for a subsequent drying step. A straightforward methodology for the determination of the free lime content and of the water amount to be added has been developed and validated. Hydration trials have been carried out to study the respective impacts of the dust nature, the temperature and added water on the reaction kinetics. Industrial trials have confirmed that the behaviour is the same at pilot and industrial scales.

Slags / 147

Recycling of blast furnace sludge by hydrometallurgy process

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Although its chemistry rich in valuable raw materials: carbon content up to 60% and iron content of up to 30 %, blast furnace sludge cannot be recycled into the sintering process, because of its Zn content which is detrimental for Blast Furnace operation. Without an economically viable solution to the problem, millions of tonnes of sludge goes to landfill, creating costs for steelmakers who are grappling with increasingly stringent environmental regulations around waste management. Hydrometallurgy allows the selective removal of Zn and Pb from the sludge, which can then be recycled at the sinter plant and the heavy metals can be sent to the zinc industry for recycling and reuse. After concluding laboratory tests, one small pilot unit designed by Paul Wurth was used to assess the feasibility of the process a bigger scale.

The pilot tests have successfully demonstrated the feasibility of hydrometallurgy treatment for various types of blast furnace sludge. Both concentrates (carbon/ iron and zinc/ lead) produced during hydrometallurgy process met the technical and chemical requirements needed to recycle. For carbon and iron concentrate recycled to the sinter plant, Zn content remains generally below 0,3% and the lead below 0,1%. From an environmental perspective, the results showed that the air pollutants and effluent water from the process after treatment remain below the legal requirements.

Sintering & Pelletizing / 148

Sinter-cooler process CFD modeling

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Sinter-Cooler process aims to cool down material at sinter-strand outlet to safely transport it to blast furnaces. In a context of high productivity of sinter-strands, good operation of this process is a key feature to avoid productivity loss and fire issues on conveyor belts. Numerical model was

developed to find optimal operating conditions to be applied by operators to maximize capacity of the Sinter-Cooler. 2D numerical model includes Darcy-Forchheimer equations to simulate cooling air flowing inside porous medium (i.e. sinter-bed) and uses 2-temperatures continuous solid model coupled with heat transfer coefficient correlation to integrate heat exchange between sinter-bed and cooling air. This Sinter-Cooler model was validated using heating-cooling experiments in a laboratory sinter-pot. A sinter bed was heated up to around 850°C before being cooled down by fresh air. Several thermocouples located inside sinter particles were assigned at various locations inside the sinter bed and were used to measure solid phase temperature. Fluid phase temperature was measured using other thermocouples located as well at the top as inside of the sinter bed. Air flow rate and pressure drop were also monitored. Other parameters such as height of sinter bed (H ; $2/3 H$), sinter particle size (10 to 40 mm), flow rate ($1000 < Re < 10\ 000$) and boundary conditions were considered. Experimental and numerical cooling curves were compared and showed good accordance. Simulations were run based on industrial conditions. Influences of different parameters (height of bed, speed of cooler, air-leakage rate, etc) were investigated. These results provide valuable information to maximize capacity of sinter-cooler accordingly to sinter-strand process configuration.

Cokemaking / 150

Influence of pre-treated biomass on the microstructure of metallurgical coke

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The renewable biomass can be applied in the steel industry mainly by means of injection, gasification and mixing or embedding into raw materials, and contribute in such a way to the CO₂ emission mitigation. Previous studies on the biomass usage in cokemaking concluded that a maximum amount of raw biomass in coal blend is limited to some 1.5 – 2.0 % due to deterioration of coke quality. To investigate the possibility to shift the biomass limit to higher values, recently different types of pre-treated biomass, i.e. woody pellets and biomass residues, were mixed with coal and coked in a laboratory muffle furnace, Pre-treatment was done under inert atmosphere in a temperature range between 300 °C and 1200 °C. This study focuses on the investigation of the influence of pre-treated biomass on the microstructure of metallurgical coke and the connectivity between coal and biomass particles during the cokemaking process. It seems to be a crucial mechanism responsible for coke strength. Pre-treated biomass and coal were put in layers one on top of the other beneath a burden for 24 hours at a temperature of 1050 °C to simulate the industrial cokemaking process. After that the boundary layer of both biomass and coal in the produced coke have been examined by microstructural analysis using an optical microscope combined with imaging analysis software to investigate the connectivity and the porosity of coal- and biomass-originated coke structure. Based on the results, conclusions are given on an optimal usage of biomass in cokemaking.

Industry 4.0 / 151

Indoor positioning of steel ladles using beacons

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Indoor positioning of steel ladles using beacons

In recent years significant progress has been achieved in the field of Bluetooth technology. While the Bluetooth functionality is well-known since the 1990s, it was recently that new application scenarios have occurred originating from the energy saving Bluetooth version BLE (Bluetooth Low Energy, Bluetooth Smart). Since GPS does not work indoors, the Bluetooth beacon is a good alternative for indoor positioning in a steel plant. The beacon is cheap, runs on button cells up to years and has a maximum indoor range of 70 - 100 m. On the one hand, the beacon can be used in client based solutions, that is to say positioning via a mobile application (App). On the other hand, a server based positioning solution is possible as well. For ladle positioning, 2 - 4 beacons have been mounted onto the ladle steel shells in a steel plant. The beacons transmit unique signals by which the mobile application determines the current ladle position. In case of the client based solution the application is running onto the smart device itself. In case of the cloud based solution the Application is run onto a Federation server. The paper describes the basic layout, results and benefits of the beacon solution in the steel plant.

Blast Furnace Ironmaking / 152**Influence of injection of pre-reduced iron ores on the processes in the blast furnace raceway**

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Coupling the blast furnace with direct reduction processes may increase the BF productivity and flexibility, and contribute to CO₂ emission mitigation at an integrated steelworks. Charging of HBI into blast furnaces will be realised this year in Europe. Another way is injection of DRI / LRI via tuyères. In this case, the briquetting step and long residence times in the shaft could be avoided. This study focuses on the reaction behaviour of DRI / LRI fines during injection into a blast furnace by means of the laboratory injection rig MIRI and pilot plant COBESI (Coke Bed Simulator) as well as by mathematical modelling. The effect of particle microstructure, metallization and reduction degrees on reoxidation behavior is discussed. The influence of carbon presence in the pre-reduced material on its conversion and reoxidation under the raceway conditions was investigated. Pilot tests primarily aimed at interaction between injected DRI / LRI and coke in the lower blast furnace zone. Among others, change in coke reactivity was examined. Furthermore, co-injection of iron containing dusts with PC is discussed. Flame temperature while injecting various DRI/LRI-types was calculated using a developed model.

Energy Management & Recovery / 153**i.Process/Steel-RHF: An adaptive algorithm aimed at on-line optimization of re-heating furnaces**

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Nowadays, energy efficiency represents the main challenge in iron & steel industries. The key aspect for the achievement of this crucial specification is constituted by the optimization of the involved billets reheating and rolling processes. In particular, the major difficult is the need of a

concurrent and coordinated optimization of the reheating furnaces and of the rolling mill stands. For this purpose, most control systems exploit several groups of heating curves, obtained from offline modelling procedures. In these solutions, the lack of an adaptive framework is observed. i.Process/Steel-RHF represents the first Advanced Process Control (APC) system for reheating furnaces based on an adaptive Model Predictive Control (MPC) strategy: the patented adaptive constrained multivariable control algorithm exploits an optimal prediction of all the reheating furnaces variables, leading to an optimized management of all furnace conditions. Different modelling techniques have been used: black-box identification techniques have been employed for the furnace variables (i.e. furnace zones temperature, valves positions, temperature difference between adjacent furnace zones, smoke-exchanger temperature, oxygen contents), while a parameter varying first principles model has been developed for each billet that is located in the furnace. i.Process/Steel-RHF APC strategy allows an adaptive multivariable optimization of reheating furnaces, able to guarantee optimal operating points in all process conditions. It assured a specific fuel consumption decreasing in the range 3% - 7% in all the current applications, with a service factor greater than 95 %. The global reheating furnaces operating framework assures a coordination with the rolling mill phase. In October 2015 i.Process/Steel-RHF APC system has been awarded as the most innovative energy efficiency project in Italy, because it successfully addressed the problem of holistic optimization of a reheating furnace enslaved to a rolling-mill.

Cost & Process Control / 154

Cleanliness measurement and control using innovative LIBS method

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This paper presents the work carried out by CRM Group in view to measure on-line the cleanliness of steel strip at the exit of the cleaning section of galvanizing lines. The applied method is based on the LIBS principle (Laser Induced Breakdown Spectroscopy) and allows a simultaneous measurement of the iron fines and of the carbon pollution. A short comparison with existing measuring systems is given and the advantages of this new technique are highlighted. The paper also describes the methodology used and the improvements made in order to achieve an accurate determination of the low pollution levels expected after the cleaning section. Finally, some results are presented on samples processed in different conditions on the CRM Group pilot line. The sensitivity and precision of the method are also quantified and the potential applications in galvanizing lines are explained as well.

Sintering & Pelletizing / 155

Granulation of ultra-fine ores for utilization in iron ore sintering

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Altering qualities of raw materials for iron making demand changing treatment before using them in metallurgical aggregates. The conventional iron ore sintering process is only suitable for materials down to a particle size of about 0.2 mm. Currently, it is possible to achieve a maximum fine ore amount of up to 180 to 200 kg/t sinter. In this study, the influence of ultra-fine iron ores (< 0.1 mm) on the permeability of the sinter mixture was investigated with its amount up to 500 kg/t sinter. The sinter mixtures were first mixed and then granulated with an Eirich intensive mixer with different mixing tool velocities and loadings for these two steps. The used

mixture contains two sinter feed ores and one iron ore concentrate, fluxes, coke breeze as fuel and return fines. The particle size distribution was investigated by conventional sieving methods. Additionally, the particle size distribution of the granulated agglomerates after drying has also been measured. It was found that an increasing content of ultra-fine ores resulted in a mixture with smaller agglomerates. Also, the bigger particles in the mixtures with lower ultra-fines content were able to adhere a bigger amount of the smaller particles. Permeability tests were performed in a lab rig in which the pressure drop of a bed with a constant volume flow of air have been measured. The results showed a decreasing bed permeability with increasing ultra-fine ore rate at constant water content.

Applications & Galvanizing / 156

Optimisation of zinc coating using shape, position and vibrations high precision system

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CRM has developed a very precise method to measure the shape and vibrations just above the wipers on galvanising lines. Based on mirror-principle, this method allows to reach 0.1mm precision in position and 50Hz in vibrations and is adjustable to a wide range of wipers. The measurements done can be used to control the shape and vibrations of strip leading so to a better coating homogeneity and allowing producers to increase its product quality.

Secondary Metallurgy / 157

Macroscopic texture examination of huge polished micrograph sections for validation of remelting simulations

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The meaning of numerical simulations of metallurgical reactors has increased during the last years. The simulations offer detailed information about the process and new insights into regions, which are typical difficult to examine. For the simulated remelting processes the growth direction of the dendrites is most important. The correlation between liquidus isothermal and growth direction allows the comparison to metallurgical samples produced in the real process. The validation of numerical simulations concerning measurable target values is indispensable for the expressiveness of the model. For the comparison of the dendrite growth direction it is necessary to investigate the microstructure of the whole ingot diameter. An in-house development, the "macroscopic texture examination", allows to scan huge metallurgical samples including the evaluation up to secondary dendrite arm spacings. The technic is based on a high resolution reflex camera with a macro lens mounted on a traversing unit. The single photographs are stitched to a picture of the whole sample. On the basis of the determined dendrite growth directions a pool profile can be reconstructed and compared to the numeric model.

Rolled Properties and Characterizations / 159

Review of CRM sensors usable for improved coated products

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A series of measurement systems have been developed by CRM during last years. This covers measurements from entry to exit of galvanising line. These measurements cover: oxide thickness measurement for oxydo-reduction control inside furnace, the shape of the strip inside furnace to control heat buckles, the position of wipers and the shape and vibrations of strip at bath level to control zinc coating homogeneity, characterisation of galvanized product if produced, roughness and waviness systems to control the final product surface quality. All the measurements answer to the more and more high quality level requested by the customers. Highlights will be given on how to use these measurements, what is their precision and what are the advantages of each one for industrial lines.

Rolling / 161

Process model development for reheating plants using simple numerical methods enhanced with CFD results

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Beside computational intensive methods like CFD or FEM, reduced modelling approaches for technical process may be more practical, especially in production environments. A modelling approach, which can be applicable for industrial processes to predict the heating of products, semi-finished materials or raw materials, will be shown. To derive such models many different approaches, depending on the requirements of the model, can be used. Typical approaches are the direct usage of simplified physical equations, the usage of artificial intelligence methods, regressions techniques as well as mixtures of those approaches. Another possibility, which will be described here, is the usage of results derived from more computational expensive physical simulations and using these as boundary conditions for less expensive models. This can be useful, where the influences of the reduced model parameter are small regarding the more complex physical behavior and may be a valuable alternative to more extensive measurement campaigns. For example, this method can be used to predict overheating, possible hot cracking locations or unnecessary energy usage in several heating processes. As an example a self-developed process modelling software, which can be used to predict the heating of block staples in a block reheating plant, will be shown.

Electric Arc Furnace / 162

Adaptive EAF online control based on innovative sensors and comprehensive models

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The scrap used as charge material in the Electric Arc Furnace (EAF) is characterised by a high variability in yield, chemical composition, bulk density and melting behaviour. This is essential to be considered in context with online monitoring and control of the EAF process. The objective of the Pilot & Demonstration project AdaptEAF, funded within the European Research Fund for Coal and Steel (RFCS), is to develop and test an innovative EAF process control, which adapts to the varying scrap properties, striving for reduced total energy consumption and improved

melting yield, and thus also for an increased productivity of the EAF process. Novel sensors and measurement systems in combination with evaluation algorithms are used to monitor the properties of the actually charged materials. An imaging system is used to estimate the filling level of the scrap baskets just before charging into the EAF. From the effective density of different scrap mixes the mean bulk density of the individual scrap types is derived. Vibration sensors at the furnace vessel are applied to monitor the scrap melting progress. For determination of steel, hot heel and slag amounts a dip sensor to measure steel and slag levels is used, and an imaging system to monitor the bath level in the furnace has been installed. This additional process information is used to enhance the functionality and prediction accuracy of previously developed dynamic energy and mass balance models for online monitoring of the EAF process status, including the continuous follow up of the hot heel amount. Furthermore the model was extended by a detailed slag balance calculation, considering besides slag former additions all oxidisable elements including iron for a metallic yield calculation. Slag weight and analysis are calculated throughout the meltdown phase and the refining phase of the EAF process. The online information on bath level, steel and slag amount, scrap melting progress, and energetic behaviour is used for model-based online control of scrap charging as well as chemical energy input via burners and oxygen injectors. The electrical and chemical energy inputs are balanced for optimised energetic performance and maximised metallic yield of the charged materials avoiding yield losses by excessive oxidation. The furnace practise is optimised regarding the timing of scrap charging as well as steel bath level and slag amount. In addition, with the help of the slag balance calculations an existing statistical model for determination of the EAF charge material properties has been improved significantly. Thus the content of oxidisable elements like Mn, Cr, etc. in the different scrap types in use can be estimated with higher accuracy. This also improves the reliability of an existing charge mix calculation, to achieve the target EAF tapping analysis with minimum charge material costs. The innovative, adaptive EAF process control is applied, tested and evaluated under industrial conditions at the well-equipped and instrumented 140 t DC Electric Arc Furnace of Georgsmarienhütte (GMH).

Secondary Metallurgy / 163

Real time sensing, dynamic modelling and advanced control of melt temperature in liquid steelmaking

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The process of liquid steelmaking is characterised by a large throughput of resources and energy. It is performed along a chain of different batch processes performed consisting of several aggregates for heating and metallurgical refining of the liquid steel melt. The objective of the production process is to deliver liquid steel melts with narrow quality targets regarding temperature and chemical composition at a predefined time to the continuous casting plant. Within the research project RECOBA, which is funded in the SPIRE part of the HORIZON 2020 research programme, the real-time control of the batch process chain for liquid steelmaking is enhanced with focus on the steel melt temperature by application of novel sensor techniques, predictive process models as well as innovative process control and optimization tools. Fibre optical temperature sensors with an extremely short response time, high precision and continuous operation for several minutes allow an in-line measurement of the liquid steel temperature. Detailed process models which consider the interactions and interdependencies between the different batch processes as well as the thermal conditions of steel ladles and degassing vessels allow an accurate real-time monitoring and prediction of steel temperature evolution along the whole batch process chain of liquid steelmaking. For process optimization and control the process models are combined with innovative control tools as non-linear state estimation, Model Predictive Control and iterative learning techniques,

to ensure an energy and resource efficient achievement of the narrow target temperature window at the end of the batch process chain. The sensor development is performed by MINKON Poland with support of VDEh-Betriebsforschungsinstitut, which is also responsible for the development and application of process models as well as control techniques. The sensors, process models and control concepts are developed with the support of thyssenkrupp Steel Europe.

Blast Furnace Ironmaking / 164

Mathematical model dedicated to the diagnosis and optimization of blast furnace hot stove battery operation

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In recent years, efforts in the field of ironmaking research have been focused on the process optimization to reach new objectives in terms of low reducing agent operation. As a consequence, mathematical models have become key tools, including advanced numerical methods, to describe accurately physical phenomena occurring in the blast furnace. However, little attention has been paid so far to the description of the hot stove battery, whose optimization also impacts blast furnace performances in terms of consumption of reducing agent. A new modeling of the hot stove battery has been developed to provide an offline optimization tool to the industrial operators. This model is based on a 1D description of the thermal phenomena in the hot stove, such as heat transfer in the checker-work and gas combustion. According to a set of process measurements, main overall characteristics of each stove, like inertia as well as heat transfer efficiency, are calculated by a reverse method. Based on the identified reference state, a complete set of potential stove battery working points can be simulated, to find the most optimal configuration towards the expectations of the plant. As a consequence, the methodology differs from an on-line expert system, as it is focused on the analysis of the battery during a stable working point to simulate prospective process optimizations.

Blast Furnace Ironmaking / 165

New hearth design for blast furnace no. 3 at DK

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DK Recycling & Roheisen operates its blast furnace No. 3 with zinc loads higher than any other blast furnace in the world, because the metallic feed consists of iron and zinc containing residues of the steel industry.

During the last year, the phenomena of the furnace lifting itself more than 200 mm out of its foundation could be observed. This led to dramatic consequences in operation and had to be solved by a complete relining of the hearth as well as the foundation.

The paper describes the reasons for the furnace lifting as well as a detailed description of the new hearth concept and the execution of the work in summer 2016.

Blast Furnace Ironmaking / 166

New top charging unit for Zaporizhstal

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Blast furnace No. 3 at Zaporizhstal in Zaporozhye is rebuilt in 2016-2017. The Ukrainian company is targeting for increased production and availability by the use of new technology. Zaporizhstal awarded the contract of the Top Charging Unit to Danieli Corus, after comparing all available technologies. Main focus of DC is availability and maintainability of equipment. The DC product is a combination of new technology with traditional robust solutions. The hearth of the TCU is the chute type charging devices which has proven to offer optimum control over the distribution of raw material on the stockline, however based on a different tilting technique. Reliability of the chosen charging device is pivotal, as it largely determines availability of the blast furnace and requires long outages in case exchange is required. This article describes the DANCU (Danieli Charging Unit) - a robust hydraulic system. This chute type charging unit has only four major moving parts, none of which is complex or vulnerable. It also describes main project challenges - the use of hot sinter and the short project schedule.

Blast Furnace Ironmaking / 167

Industrial application of blast furnace liquid levels measurements using strain gauges

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A real-time liquid level measurement system was installed at Dillinger Hütte Blast Furnace No 5. The method is mainly based on strain gauges along a vertical line on the lower BF shell and an analytical deformation model of the hearth. The method, developed by TMT and CRM, indicates both the total slag level and the pig iron level inside the BF hearth.

The liquid level measurement allows to improve the tapping strategy by optimisation of the tap-to-tap time. In addition, the analysis of the trends serves to understand the relationship of liquid volume to level, and to evaluate the coke voidage in the BF hearth. The maximum liquid level is known so to guarantee a minimum gap to the tuyere level, to minimize the risk of slag arrival to the tuyeres. It further serves to optimize the tapping parameters, such as the drill bit diameter and the clay mass compound, by analyzing how the taphole throughput and diameter evolves during tapping.

Compared to mass-balance models, only few parameters need to be known, for instance, there is no need for taphole parameters, the slag arrival time or the coke voidage. Compared to EMF methods, the strain method is not depending on the hot metal temperature, the measurements are considerably more stable, and the level of both liquids are measured.

Blast Furnace Ironmaking / 168

Hot blast stove campaign extension repairs at operating temperature

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Hot Blast Stove Technology has been developed to such an extent that low cost hot metal production for over 30 years without major repairs has become achievable, making the decision for a campaign length between 5 to over 30 years a design choice for the plant owner/operator.

Some of the earlier examples of designs capable of such long campaign lengths are currently close to the 50th year of their running campaign. These examples are found especially in Europe and North America. This article discusses operational and maintenance experiences over these exceptionally long campaigns as well as a number of approaches towards campaigns extension of hot blast stoves individually and hot blast systems in their entirety. Recent experiences such as post mortem findings after such long campaigns and hot intermediate repairs, while keeping the majority of the system at operating temperature, are also discussed.

Electric Arc Furnace / 169

Analysis of time delay in heat transfer caused by slag accumulated on EAF side panels

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When the scrap charge in EAF melts, the heat transfer between the arc and side panels increases until slag foaming is started or arc length is reduced. However, the slag accumulated on the side panels acts as a kinetic barrier between the arc and cooling water. Previously, only estimates of the cause of slag has been obtained due to lack of reference measurement. In this work side panel cooling water temperature gradient is compared to optical emission spectrum gathered with optical fibers through EAF roof. The data used in the analysis was obtained from simultaneous measurement of three EAF hot-spot optical emission spectra conducted at Outokumpu Stainless Oy, Tornio Works, EAF 2 in 2015. The time delay between thermal and optical signals was analysed with cross-correlation method and signal change detection. The delays were calculated for over 100 heats to estimate the length and variation of the delay caused by the accumulated slag. The results from the different methods were evaluated to find the most accurate description of time delay. The results indicate that cross-correlation method gives the most stable results. The average delay calculated with the cross-correlation method was approximately 80 seconds in the upper and 100 seconds in the lower panels.

Long Products / 170

LLR Rolls - New design concept for composite rolls and innovative ring locking system

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PERT has developed and patented a new concept for the composite rolls for long product rolling mills, called LLR Rolls (Long – Life Rolling Rolls). LLR Rolls, allows mounting of cast iron, HSS or carbide rings on a shaft made of special alloyed steel, in order to increase the grooves working life and to decrease, consequently, the plant downtimes for stands changing operations. The transmissible torque is also highly increased due to the use of steel ring-holder shaft making theoretically impossible the roll neck failures. The new and patented ring locking system is the main advantage introduced by LLR Rolls, as the using of traditional hydraulic locking system is avoided as well as the mechanical pins or keys. In fact, the torque is transmitted from the shaft to a special designed spacer and from the spacer directly to the rolling rings. A mechanical coupling between shaft and spacer and between spacer and rings is used, so the torque is transmitted not by friction, as per hydraulic locking system. Thanks to the above mentioned innovative locking system, rings changing operations are extremely easy and faster to perform, avoiding the use

of any hydraulic or heating tool. In addition, the slipping of the ring is impossible also with high rolling loads, due to the mechanical coupling of the group shaft-spacer-rings. Avoiding the hydraulic locking system and practically avoiding a longer thread on the shaft (used to pre-load the shaft, permitting the torque transmission by friction), which occupies a lot of space, it is possible to utilize almost the full rolls barrel length, increasing the number of grooves, decreasing, in this way, the plant downtimes due to stands replacements. In addition, LLR Rolls doesn't need a very high axial locking force, so the shaft damages are totally avoided.

LLR Rolls consist of:

- Heat treated ring – holder shaft, made of alloyed steel
- Patented ring locking system and spacer
- Rolling ring (cast iron or carbide)
- Ring nut for axial clamping

The main advantages introduced by using LLR Rolls, are :

- Patented coupling between rings and shaft
- Mechanical locking system instead of hydraulic system
- Lower plant downtimes
- Increased productivity of the rolling mill and excellent surface finishing of final products through precise dimension control during rolling
- The shaft can be reused, only the worn ring must be replaced.
- Improved quality and tolerances of the final products, thanks to the use of carbide rings
- Reduced number of rings as a spare (compared with cast iron rolls)
- Free from ring slippage even under high rolling torque
- Simple assembling and disassembling operations for rings changing

Surface Technologies / 171

Automatic surface inspection in steel products ensures safe, cost efficient and timely defect detection in production

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Here we present the HiNSPECT, a brand new machine based on shape-from-shadow technique, which aims at marking defective areas product surfaces with high accuracy within the zero-defects tolerance policy. Special lightning and innovative algorithms concur to highlight the defects with their pseudo-3D depth. Irregularities, such as scratch marks or inclusions, can be neatly seen in real-time without the need of reinspecting offline: small defects (less than 1 mm²) have been correctly located on the product surface with high-resolution images of hot/cold rolled products and displayed to the operator.

Advanced Rolling / 172

HiPROFILE innovative defect detection package to increase production quality

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Due the increasing requirements for an integrated system for dimensional measuring and defect detection, Danieli Automation has recently developed an innovative defect detection algorithm. Based on the data grabbed by the same high speed cameras also used for profile dimensional control, it builds a complete production quality assurance package. A high density and accurate 3D surface of the product is obtained by thousands per seconds complete profiles acquisition of the bar. The new adaptive algorithm creates a defective area map of the surface and dynamically follows its behaviour. False positive defect indications are dramatically reduced and detection sensitivity is continuously adjusted to best performance

Byproducts / 173

Water process integration: Assessment of an ultrafiltration and reverse osmosis based treatment to regenerate coke-making area wastewater

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Industry follows only the agriculture sector as main water consumer, as water is fundamental for all process steps from the cooling to the washing stages, from the product formulation to the mass separation. In particular, steelworks use significant amount of water in cooling and washing systems. However, higher freshwater cost and environmental regulation pressurise industry toward an improvement of the efficiency of water usage, which can be achieved, for instance, by reusing, recycling and regenerating wastewater. These are the principles of water process integration that can allow achieving a reduction of the water footprint of a process chain, such as the steelmaking one. To this aim, the paper presents a work carried out in cooperation with an Italian Steelworks that is focused on the evaluation of the possibility to reuse the wastewater coming from the coke-making area after a regeneration treatment. The work is part of the project entitled "Efficient Use of Resources in Steel Plants through Process Integration" (REFFIPLANT), which is funded by the Research Fund for Coal and Steel of the European Union, and consists of a first modelling and simulation step, of an experimental stage and of an economic assessment. A treatment process that consists of ultrafiltration and reverse osmosis as main steps was assessed in order to remove the main contaminants (e.g. iron and manganese salts, ammonia, free cyanide). Firstly, a model was developed using the WATERint® simulation software in order to have a first idea of the suitability of the proposed process scheme to obtain high quality water to be internally reused. Satisfying results paved the way to the development of a pilot plant and to its use to make real field tests in order to optimize the configuration scheme considering if each step is necessary and if some chemicals additions are required: contaminants amount, pH, electrical conductivity, hardness were monitored. The experimental campaign confirms the simulation results, proving that a process consisting of ultrafiltration, an ammonia removal stage and reverse osmosis allows obtaining a water of suitable quality to be reused in the coke-making area. The obtained simulation and real tests results were finally used to evaluate the economic feasibility of the proposed water treatment process through the payback period analysis depending on the variations of the permeate and retentate streams prices.

Electric Arc Furnace / 174

Modeling of steel bar melting process in an experimental induction furnace

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The steel scrap melting rate in an electric arc furnace (EAF) is directly related to energy consumption and furnace productivity. In this paper, the melting time of steel bars of varying size in a liquid steel bath has been predicted using computational fluid dynamics (CFD) simulation. A three-dimensional CFD model has been developed with detailed consideration of fluid flow and the melting process. An enthalpy-porosity technique is applied, using ANSYS Fluent to model the scrap melting process. The simulation results are in good agreement with experimental data on both the steel bar melting profile and the melting time. The model can be applied to investigate the flow characteristics, temperature field and scrap melting process in the steel bath during the EAF operation.

Environmental / 175

A simulation assessment of modifications of the water network of an electric arc furnace steelworks to allow wastewater reuse

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The sustainability of the electric steelmaking route is affected by several factors, such as the electric energy consumption, the waste production, the CO₂ emission, as well as by the consumption of freshwater and the amount of wastewater. The improvement of the water management in the electric steelworks can lead to a reduction of their water footprint and impact on the surrounding environment and local community. To achieve this goal, the paper presents a work focused on the assessment of modifications of a water network of an Italian electric steelmaking plant in order to reduce the contaminant load of wastewater and allow its internal reuse. The work is part of the European project entitled "Environmental Impact Evaluation and Effective Management of Resources" (EIRES) funded by the Research Fund for Coal and Steel. Fluoride is the main contaminant that limits the possibility of the reuse of wastewater; it comes from the lubricant powder used in continuous casting and it contaminates water used for direct cooling of the product in the casting machine. For this reason, some solutions of treatment units addition to the current steel water network were evaluated. Sensitivity analyses were also carried out to evaluate the process behaviour to possible variation of features of the water to be treated. The evaluation was carried out by exploiting a simulation tool developed during the project through Aspen Plus® and especially its sub-model related to the water network. The main water parameters were monitored such as electrical conductivity, contaminant amount, pH and temperatures. The reuse of treated wastewater was then considered and some KPIs related to water consumption before and after the evaluated water network modifications were evaluated and compared.

Industry 4.0 / 176

Using numerical simulation and virtual reality visualization for steelmaking applications

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Numerical simulation methods such as Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) are increasingly used in the steel industry to provide quick and economical tools for problem-solving and design. Game engines such as Unity 3D have become important tools for developing interactive applications such as serious games and training applications. However, little work has been done to integrate CFD and FEA into modern game engines. This paper describes a methodology for integrating CFD and FEA simulation results, with 3D models of equipment and interactive steelmaking processes using the Unity 3D game engine. Three applications are also discussed which include: CFD and FEA simulations used for energy optimization and training in the use of an overhead crane used to transport large ladles of liquid hot metal between processes during the making of steel; FEA simulations for an interactive application to troubleshoot a vertical edger failure, used to reduce the thickness of rolled steel; and interactive training using CFD simulations inside of a blast furnace, used to heat and reduce iron ore to pig iron (liquid hot metal). This paper also demonstrates the end products which are virtual reality software utilizing technologies including: Oculus Rift, Google Cardboard, and immersive projection systems.

Long Products / 177

New sizing stands for bar and wire rod mills, to achieve tighter tolerances - the BSS stands

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Thanks to the extremely high stiffness of BSS Sizing Stands, we introduce the concept of “sizing stands” not only in special steel rolling mills (SBQ or alloyed steel), where the tolerance of the final products must be very tight, but also in rebar or wire rod rolling mills. This means a very high final product quality and a better product marketability, in fact the quality improvement does not involve higher production cost, even better, using BSS Sizing Stands, the operational cost are reduced. In the modern market, the flexibility in the production range becomes a relevant factor for the increase of market shares or even for the survival of the plant. Precisely for this purpose, BSS Sizing Stands gives the best flexibility to the rolling mill, in fact a rolling mill which was born for rebar production, could be easily upgraded and converted in to a special steel rolling mill, for the production of high valued steel grades. In the finishing mill, installing the BSS Stands with a shorter barrel length (monogroove) and tungsten carbide rolling rings, a final tolerance of 1/6 DIN can be easily achieved. Furthermore, a block of 3 BSS Stands, can be used as a sizing block, in Horizontal – Vertical – Horizontal arrangement, with a dedicated roll pass design made of oval – round – round sequence. All the bar sizes will be rolled and finished on the above mentioned block, adopting the “single family” roll pass concept, regarding the roughing, intermediate and pre-finishing mill. In wire rod mills, it is very important that the entry stock of the fast finishing block, have not only the required section and the required diameters as per roll pass design, but especially must have a constant section all along the whole bar. This is a key factor for the final quality of the wire rod, in fact if the section of the entry round bar is not constant, the low section reduction ratio in the finishing block may not be able to correct such shape defect, resulting in a poor quality which is not acceptable especially if the wire rod will be processed in a drawing lines. The installation of a 3-stands sizing block made of BSS Stands before the wire rod finishing block can be a very good solution for high quality wire rod production, guaranteeing an entry bar already with tight tolerance.

The stiffness and the rigidity of the BSS Sizing Stands are due to:

- Ring-holder shafts mounted on double support
- Eccentric gap regulation, which allows the gap setting every 5 μm
- Rolling load distributed on stand housing (monolithic), so the reaction surface is increased respect other common stands (no tie rods or cantilevered rolls)
- Shorter stress path compared to housingsless stands

- Flexotorsional problems practically eliminated, due to the double support and the patented ring-holder shaft design
- Unique design for the elimination of the bearings backlash, for a better control of the final tolerances and for a perfect bar shape. In fact, the backlash of the upper bearing of the Horizontal stands is eliminated as well as for both bearings in Vertical stands.

Of course the rigidity of BS Stands means the achievement of very tight tolerance on the rolled stock, but it involves other advantages, such as:

- 1) Final product tolerance up to 1/6 DIN
- 2) For each billet, the rolled bar incoming and outgoing of each passes has almost the same section, also if the starting temperature of the billet is different (colder billet causes higher mechanical yielding and section changing), so the stress of the guides is reduced and their working life will be increased.
- 3) Possibility of performing thermo-mechanical rolling
- 4) Increased head-to-tail tolerance
- 5) Possibility to produce more added value products even in a rebar rolling mill, installing the BSS Sizing Block or replacing the rolling unit of existing stands with a new BSS rolling units designed in order to fit in the existing mills.

Cokemaking / 178

Steel plant integrated charcoal production from wood and kraft lignin – Feasible market conditions

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Steel production is responsible for roughly 8% of the global CO₂ emissions and due to its projected growing worldwide demand, this figure can be expected to grow further. As modern steel production has been optimized over the last decades close to its thermodynamic and –chemical limits, considerable reduction of CO₂ emission and energy demand by process optimization are considered difficult to achieve. One option to reduce CO₂ emissions is to partly replace fossil coal and coke with renewable charcoal. Biochar produced via slow pyrolysis to be used as a reducer in a blast furnace seems to be the most beneficial pathway. This is due to the high quality of the yielded charcoal, its process maturity and the relatively low investment cost of the slow pyrolysis equipment. The objective of this study is to establish mass- and energy balances of a steel plant integrated with a slow pyrolysis process to produce charcoal to be injected into the blast furnace. Therefore a simulation model of a reference steel plant is modelled based on real operation data. A mathematical model is applied to calculate a closed mass- and energy balance of the slow pyrolysis for lignin and wood. The slow pyrolysis model is based on experimental results carried out by the Technical Research Centre of Finland (VTT). In order to maintain high steel quality, maximum biochar injection rates are defined considering the different price scenarios for biomass feedstock and CO₂ emission certificates. The results of this study give feasible market conditions at which the use of biochar from wood and lignin as a reducing agent is economically beneficial. Results show that, at the current price of CO₂ emission certificates, the use of charcoal is not economically feasible even though the CO₂ reduction potential is in the range of 10% compared to the reference plant.

Oxygen Steelmaking / 179

TBM tuyeres arrangements and flow – comparison between BOF thyssenkrupp CSA and cold model

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The technological knowledge of BOF process represents an important key to improve metallurgical results. In a challenging and competitive market, operational stability and innovation are necessary to achieve excellent quality and suitable costs. In order to study the combined blowing (top and bottom blow) through cold physical model, in similarity with thyssenkrupp 330 tons converter, visual inspection and colorimetry methods were used to define the jet penetration and the best TBM tuyeres configuration on the metal bath behavior, as the main objective in the present work.

Oxygen Steelmaking / 180

BOF pressure effects over jet penetration at TKCSA

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BOF, due to operational conditions and location, suffer variations in the parameters whose effects on the liquid bath are usually neglected. The present paper investigated mainly two aspects: inner BOF pressure and oxygen temperature in the stagnant reservoir. The results shown that oxygen temperature changes properties like density and velocity but has small influence on jet penetration. The BOF pressure has significant influence on jet penetration and creates a new dilemma regarding nozzles dimensions considering overexpanding and underexpanding jets

Slags / 181

Modelling of basic oxygen furnace slag treatment and processing in order to evaluate possibility of their reuse

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An increased environmental consciousness, more stringent environmental regulations and a raise of raw material costs have characterized the last few years. All these factors affect the industrial

chain management and in the case of the steel industry lead to an intensification of the effort to find solutions allowing increasing waste and by-product reuse. The paper presents part of the work carried out in this direction within the European project entitled "Removal of Phosphorus from BOF-slag" (PSP-BOF). Such project aims at obtaining reusable fractions of material from the Basic Oxygen Furnace (BOF) slag. In particular, the paper is focused on the modelling work carried out to develop models that include slag treatment, slag processing and production of reusable products. To this aim, two kind of models were developed and presented. The first model is more complex, considers each treatment process step and allows sensitivity analyses in order to get useful information in case of different slags to be treated or different treatment configurations. The other one is only a material flow-based model that, using the results obtained by the complex model and by the experimentation, which was carried out in pilot scale in a first part of the project, allows the evaluation of the best way to reuse (internally or externally) the obtained slag fractions, considering process and environmental constraints and making optimization assessment. The two developed models have been used to make comparison of the new proposed slags ways with the standard utilization route of an Italian integrated steelworks, in terms of energy and material consumption and process cost estimation, and gives indication about the best way to be followed in order to obtain both environmental and economic advantages.

Oxygen Steelmaking / 182

BOF blowing process challenges for high rate of iron ore pellet addition - Process development and results at TKCSA

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At thyssenkruppCSA, a positive heat balance at BOF process is faced, mainly because of low utilization of scrap and plant design. A singular logistic concept for hot metal transport between blast furnace and steel plant was established to optimize handling, transport and energy. An average addition of 75kg of iron ore pellets/t steel is necessary for the BOF-340t heat balance. In order to accomplish this challenge in a stable blowing process, intensive operational development have been successfully done: slopping rate reduction of 86% achieved without changing the blowing time. This paper describes the steps and results of this development.

Sintering & Pelletizing / 183

Investigation of the specific surface area and pore structure of blast furnace sinters

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Sinter is one of the most significant iron carrying raw materials in the blast furnace process. The properties of sinter such as the reducibility and the reduction degradation index (RDI) affect the efficiency of the ironmaking process directly. However, sinter is an agglomerate with complex mineralogical features and a high degree of inhomogeneity. This work aims to characterize the surface and pore distribution properties of sinter by novel characterization methods. A standardized laboratory method was developed to determine the specific surface area of different sinter samples using gas adsorption BET (Brunauer-Emmett-Teller) method. The effect of specific surface area on sinter properties has been investigated. Modern computer tomography (CT)

analysis has been used to find out the internal pore structure and the distribution of various constituents inside the sinter mass. The results have been correlated to operational properties like reducibility and corresponding RDI. This work will provide a deeper insight into the structural aspects of sinters and their behavior under process conditions.

Electric Arc Furnace / 184

SmartFurnace system and ZoloSCAN off gas monitoring integration in Vallourec Star

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With the objective to further optimize the Electric Arc Furnace process, Vallourec Star installed the ZoloSCAN Laser Off Gas Analyzer in late 2015. Being one of the most efficient EAFs in North America, the integration of the off gas sensor with the AMIGE SmartFurnace system, required precise algorithms and reliable technology in order to provide consistent results. With a design that allows virtually free maintenance and reliability, the Off Gas sensor together with the SmartFurnace system improved the EAF efficiency. This paper focuses in the scope of the installation, and the results of the dynamic heat profiles and a closed loop chemical energy control.

Electric Arc Furnace / 185

Results in EAF Process optimization with AMIGE Smart-Furnace system

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With the increasing number of high productive EAF, and the variability in raw materials and product demand, the need for a system capable of adapting to the operation conditions in real time is essential. With state of the art technology, the AMIGE SmartFurnace system, featuring optimization tools like the DigitARC PX3 Electrode Regulation System and the ZoloSCAN Laser Off Gas Analyzer, has helped improve highly productive AC and DC furnaces.

The interaction between electric power and burners, coal & oxygen injection is managed by the Electrical and Chemical Energy Input Optimization modules, which provide a flexible and open platform for operators and furnace supervisors to further improve the operation of the EAF. This paper describes the implementation of this system and results of its functionalities are shown.

New Ironmaking Technologies / 186

Rotary kilns for direct reduction of iron ore: design, operational guidelines and troubleshooting based on complex mathematic modeling

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Outotec is a pioneer in rotary kiln direct reduction with coal offering the well-proven SL/RN and the more recent SL/RN-Xtra technologies. The SL/RN-Xtra technology uses hot offgas from the rotary kiln to pre-harden green pellets on a travelling grate, before they are fed to the rotary kiln. This not only increases energy efficiency of the process, but also the production rate of the standard SL/RN module to more than 200,000 tons DRI per year per strand. Over the past years, Outotec has developed a complex mathematical in-house model to improve the understanding of kiln operation. The model incorporates complex physical and chemical phenomena occurring in the kiln such as heat transfer, granular transport of bulk material, fluid dynamics in the freeboard, and chemical reactions in bulk, freeboard, and at the bulk's surface. The model has been mainly developed for the SL/RN and SL/RN-Xtra technologies for the production of DRI as well as for Ilmenite processing in rotary kilns for the production of synthetic rutile for the pigment industry. However, the model can also be applied to other similar rotary kiln processes. To operate rotary kilns for direct reduction of iron ores in an energy efficient way within a specified and trouble-free temperature window is a challenging task due to the complex physical and chemical processes taking place within the kilns. This is why Outotec's in-house model was not only developed to design new rotary kilns, but also to provide strong support in the operation and trouble-shooting of existing rotary kilns. This applies particularly to plants where changes in the raw material occur. An important basis for all model calculations are the raw material's physical (e.g. particle size distribution) and chemical (e.g. distinctive kinetics of iron ore and coal) properties that are determined and provided by our research center in Frankfurt, Germany.

Oxygen Steelmaking / 188

Dynamic modeling of the converter off gas composition in the cooling stack

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Sustainable steel making comprises the efficient utilization of the byproducts generated during the technological process. The general byproduct generated during the converter steelmaking process is the off gas, which contains a huge amount of physical –temperature and chemical – CO and H₂ energy. The efficient utilization of both types of energy is the target of this research. The amount of generated off gas, its temperature and chemical composition, vary during the converter heats. The dynamic simulation of those parameters leads to: - An improvement of ID Fan electricity consumption; - Proper operation of the switch-over station to collect high calorific off gas; - The efficient heat utilization in the cooling stack during the off gas cooling for production of steam or hot water; - Efficient utilization of the cooling water. This research is based on the thermodynamic and kinetic modeling of the converter steelmaking process for the primary converter gas generation and CFD simulation of the gas dynamics in the cooling stack depending on different air combustion factors.

Keywords: Dynamic process modeling BOF off gas Gas dynamic simulation Air combustion factor Post combustion

Rolling / 189

Digital reheating technology - New developments and benefits

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The performance of a flat product rolling mill is directly related to the design concept and performance of the upstream reheating furnace(s), both in terms of productivity but ever more importantly for final rolled quality and yield increase purposes.

Many such production plants are also located near residential areas and thus as very demanding emissions reductions laws are set, steel processing plants must continuously adapt or risk major setbacks in their operating capacity.

This paper describes the challenges faced, design solutions adopted and new technologies introduced for the manufacture and installation of two 300 tph digital reheating furnaces for a major US steel processor.

Oxygen Steelmaking / 190

State of the art gas cleaning and utilization for BOF gases: operational results and benefits

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For cleaning of primary gases from BOF-process, the well approved wet scrubbing technology is worldwide the most applied technology. Most of these installations are running for more than 20-30 years. They were originally designed for compliance with environmental regulations much less stringent and complex than nowadays. The revamp, upgrade and retrofit of these systems to fulfil actual requirements with lowest investment and shortest shut down times is one of the main demands. For this purpose, a multi-access strategy has been developed and stepwise implemented. This strategy comprises of: - Field measurements to improve understanding of operational behavior - Technical-tests with a 1:1 scale test-rig supported by comprehensive CFD-simulations - Development of wet-ESP technology as a retrofit option - Advanced/improved control technologies to reduce energy consumption Main results of the works will be described. It has to be accentuated, that any solution has to be developed and implemented under close consideration of various site specific factors, such as available space, actual operational practice, type and make of scrubber, requested target figures.

Slags / 191

Valorisation of slag and by products from EAF-metallurgy – NoWASTE a feasible way to go?

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In Germany, 43 million tons of steel were produced in 2015, together with about 14 million tons of iron and steel slag as a by-product; about 2 million tons of which are slag from the electric arc furnace. This slag is predominantly used in road construction and earthworks in Germany; because of its significantly superior physical properties it partly substitutes natural rocks in these fields. In the long term, however, alternatives are required which enable us to utilize the slag also in other fields of application and recycle it in the plant.

With a crude steel production of nearly one million tons Georgsmarienhütte ranks among the bigger electric steel plants in Germany and is the first mover regarding energy management, environmental protection and slag utilization. Since many years the company has participated in

various public and internal research projects relating to in-plant ways of recycling for by-products to close the recovered material cycle entirely and to create products with a higher intrinsic value from the slag.

This comprises the provision of evidence that calcareous slag produced in the secondary metallurgy can be used in the electric arc furnace while partly substituting the primary resource lime, the use of biochar to reduce the CO₂-emissions, ways of using the energy potential of steel slag or the creation of totally new products from EAF-slugs and other by-products. In this regard, a context the production of a high-quality raw material for the cement industry must be mentioned; when producing it metal contained in the slag is simultaneously recovered.

These projects belong to the ongoing activities of Georgsmarienhütte GmbH to reconcile the economic and ecological challenges at the location Germany and underline our intention to be the first electric steel plant in Europe which has managed to implement the internal NoWASTE Strategy by comprehensive research and development activities.

Advanced Rolling / 192

CEM® Process : the most efficient process for thin gauge products

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POSCO has developed CEM® (Compact Endless cast and rolling Mill) process, which is based on high casting speed with 6~8m/min and endless rolling from mold meniscus to down coiler. Mechanical design improvement and high speed technology development have been achieved through various efforts such as the mold pool flow control, water cooling in the caster and the mold level hunting control. For stable change of coil thickness and width during endless rolling, the control softwares of casting and rolling have been reinforced continuously against a lot of abnormal situation, successively.

Owing to the endless rolling technology, the production ratio of ultra-thin gauge HR coils was increased significantly over 70% but, on the contrary, the cobble ratio in the rolling region was greatly decreased. Because the temperature and the speed of the strip directly after finishing mill are constant during endless rolling, the strip temperature on the run-out table for AHSS can be controlled well.

Electric Arc Furnace / 195

Bypassing problems related to water cooling – Case study for applying ILTEC in an 100t EAF

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With the ILTEC Technology, Mettop's patented water-free cooling solutions, it is possible to overcome the disadvantages of water by using an alternative cooling medium, namely the ionic liquid IL-B2001. The main characteristics, which makes IL-B2001 so favourable, are the neglectable vapour pressure, the wide liquidus range and the not flammable, non-explosive and atoxic behaviour.

Since it is well known that there are multiple reasons of creating damage caused by leaking of water cooled panels in EAF's, it is of superior interest to eliminate water as the cooling medium in certain areas: within the upper shell there might happen hydration of the refractory material caused by small leakages in the upper side wall cooling panels leading to molten steel perforation

or in the off-gas parts where there can occur cooler perforation due to corrosive off-gases. Another problem are prewear hot spots within the sidewall of the refractory lining leading to additional down time causing production losses which can be alleviated. Not to forget the priceless benefit of a safe workplace.

Using the example of a 100 t EAF, the different possibilities of implementing ILTEC are pointed out, from the bottom and the upper shell to the roof and off-gas parts of the furnace. In order to show the saving potentials, the economic benefits of increased furnace availability by implementing improved cooling solutions is provided. In addition, the benefits of increasing safety, illustrated according to different damage scenarios will be highlighted and the impact of a change to ILTEC discussed.

It is the well-engineered technology and the sophisticated process control that in the first place prevents damage based on immediate leak detection combined with the outstanding properties of IL-B2001 in case of failure or leakage that makes ILTEC creating new pathways towards safe and effective cooling.

Cold Rolling Mill / 196

Danieli cold mill complexes for automotive applications

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What makes automotive steel, really automotive? Is now-a-days automotive steel, the same as future automotive steel? And, can we reduce production costs and still achieve automotive quality? Producing steel strip with the highest material properties and surface aspects are NOT enough; CONTROL is the key aspect Danieli equipment has been developed together with:

Yieh Phui (PR China) – revolutionary Continuous Pickling coupled with Tandem Mill for thin strip production; Yildizar and Atakas (Turkey) – innovative automotive exposed cold mill complex; Tosyali Toyo (Turkey) – innovative automotive hot dip galvanizing line;

Indepth study of the automotive steel market, investment versus production costs, new design solutions for ease of operation and maintenance ensure highest final product quality. Implementation of new technology via live measurements, automation algorithms and new actuators make Danieli the answer to customer needs for highest quality and newest technology in cold mills and processing line

Keywords Cold Mill Complexes, automotive, Yieh Phui, Yildizar, Tosyali Toyo, hot dip galvanizing line

Advanced Rolling / 197

Danieli Universal Endless (DUE®) The new evolution of Danieli thin slab casting and rolling plant

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Over the last 25 years the thin slab casting and rolling process has been gaining a major market share in the production of hot rolled strip, progressively eroding the areas previously of exclusive domain of conventional mills. This is mainly thanks to the competitiveness of the process

over conventional ones, and to the growing ability of this technology to cover the majority of market niches, well beyond the boundaries of the commodity market. After having significantly contributed to the continuous expansion of this production mode and after an extensive campaign of research and physical testing in reference plants, Danieli has progressively developed over the years a new generation of thin slab casting and rolling layout, marking a new phase in the evolution of this process. The new step-ahead is a new development within the Quality Strip Production (QSP) family, which is the Danieli's strip-quality-oriented thin slab based plants. What makes this new concept different is the ability of "universal" rolling modes thanks to the fact that, now, within one single plant it is possible to perform different rolling modes, making this plant a major technology innovation compared to the previous generation. This new approach can be seen as the natural evolution of the original, successful Danieli concepts that marked the progress of the thin slab route, namely the application of the vertical curved design thin slab caster and the separation of the rolling stands into high reduction units and finishing units. Since the beginning they have represented the fingerprints of Danieli QSP technology and have become a source of inspiration for most of the recent innovations in the industry, confirming the advantages of the Danieli's original concept.

Keywords QSP, Danieli Thin Slab Casting and Rolling, Evolution, DUE®, Semi-endless, Endless

Oxygen Steelmaking / 198

Nitrogen behavior during steelmaking of high Al TRIP steels

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ArcelorMittal USA Indiana Harbor plant is making large quantity of high Al TRIP and DP grades to meet the needs from automobile industry for high strength and high deformability steel products. During steelmaking process of these high Al TRIP and Dual Phase steel grades, it has been observed that the nitrogen behaves very differently from regular Al-killed steels. Nitrogen will drop along the way of the process for high Al steels. In order to understand the mechanism, industrial heats were sampled and detailed inclusion characterizations were performed. Meanwhile, lab heats were also made under well controlled conditions to study the formation of AlN and the absorption of nitrogen in regular Al killed steel and high Al steel. This paper is attempting to document some of the preliminary findings of these studies. The basic conclusion is that the AlN inclusions form at steelmaking temperature in high Al steels and float out quickly. The floatation of AlN inclusion out of steel bath drives the nitrogen down in the bulk chemistry of the steel. The plant trials were done at Ladle Metallurgy Furnace with argon injecting facility through a lance and primary steelmaking is done at Basic Oxygen Furnace. Trials were done because steel was tapped from BOF with high Nitrogen (more than maximum allowable chemistry) because of a recycled (any off chemistry or heats which could not be cast due to operating/maintenance problem) are produced in BOF with very less Hot Metal and tends to be higher on Nitrogen (above 70 ppm).

Secondary Metallurgy / 199

Study of large size Ds type inclusions in bearing steel

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Effects of the slags on the total oxygen contents and Ds formation in bearing steel were investigated by vacuum induction furnace experiments. The optimal middle basicity slags for VD treatment

was selected in the range the CaO to SiO₂ content ratio of 3~4, and the CaO to Al₂O₃ ratio of 1.6~1.8, resulting in lower total oxygen contents and less Ds inclusions. Evolution of inclusions in bearing steel during the practical LF-VD treatment was observed. It is found that more calcium aluminates Ds inclusions appears after VD treatment due to steel and slag intensive mixing and reacting resulting in calcium content of molten steel increasing and CaO content in inclusions enhanced. The Ds inclusions observed in the finished products derived from the endogenous inclusions, the entrapped inclusions aggregated under the covering agent and entrapment of ladle slag. Combining the experiments results and the inclusions observation, the Ds inclusions can be controlled less by controlling slag, depressing the entrapment of inclusions aggregated under the covering agent and ladle slag.

Blast Furnace Ironmaking / 201

Ironmaking in Western Europe

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The blast furnace - converter route is dominant in European steelmaking. Investments are being made to modernise hot metal production plants in Europe. The coking plants, sinter units and blast furnaces are powerful and environmentally friendly. In view of the demands for massive reductions in CO₂ emissions in Europe, however, it will be necessary to work on solutions regarding whether, and how, the carbon-based blast furnace - converter route can meet such demands. Iron making in blast furnace plants has changed from “old economy” to “factory of the future”: Clean, highly performing, environmental friendly and socially sustainable.

Advanced Rolling / 202

Adjusting Hot Strip Mill Level2 Setup Using Tribological Approach to Eliminate Biting Refusal

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Strip biting is considered the most critical moment for hot rolling. Rolling could be done only if it is succeeded; otherwise the strip cannot be threaded into the mill stand and cobble will be happened due to material accumulation. The possibility of having such problem will be increased while using RGL (Roll Gap Lubrication) during the strip head biting.

Based on an empirical experience, this paper presents a taxonomy for biting cobbles during hot rolling in addition to a scientific study for determining its possible causes. In order to have a successful biting and reduce the biting cobbles, a new approach in calculating mill setup values is proposed with an empirical evaluation after applying it in Level 2 Automation system of EZDK company in Egypt.

Blast Furnace Ironmaking / 203

Importance of thermocouple layout in blast furnace hearth refractory wear monitoring

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Thermocouples are often installed in the blast furnace hearth, for use in estimating the remaining refractory thickness. However, a wide variety of thermocouple arrangements are used. Using a thermal assessment approach combining non-destructive testing (AU-E) and thermocouple data, the selection of thermocouple locations within a furnace hearth was investigated. 2D transient thermal analysis identified that the thermocouple arrangement may not identify transient changes to the system, as the thermal mass of refractory results in a slow response to process changes. It was found that 1D thermal calculations may under predict the extent of wear between thermocouples. 2D and 3D calculations were better able to predict the extent of wear. Results were later compared with AU-E measurement of refractory thickness. This assessment was used to provide recommendations to improve the thermocouple layout for refractory wear monitoring.

Blast Furnace Ironmaking / 204

Temperature fluctuation impact on structural behavior of blast furnace hearth refractory system

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During initial blow-in of the blast furnace the hearth refractory system could experience high temperatures. Over time, skull formation on the hot face of refractory results in temperature reduction within the hearth refractory. Such temperature fluctuation may generate undesirable refractory cracking and/or gap formation, particularly around ramming mixture. These flaws could increase the thermal resistance of refractory system; thus, reducing the efficiency of hearth cooling system. The higher temperatures in the hearth refractory accelerate the refractory erosion and limit the hearth campaign life. This paper presents a novel tool for assessing the impact of temperature fluctuation on the structural integrity of hearth refractory. Using this tool, locations of potential refractory damages during blow-in and blow-down of the furnace can be identified and mitigated during design stage. This tool can also be utilized in order to explain the hearth refractory wear in existing furnaces.

Hot Strip Mill / 206

Hot strip mill roll gap lubrication with low cost green oils and waste oils

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Harder grades and better surface quality in longer rolling campaigns are the today's challenges in the hot rolling finishing mill. One of the key factors to achieve these objectives is the application of roll gap lubrication. It is essential to have a high performance, robust and highly efficient industrial lubrication installation. During the last years, also the economic aspect has gained importance. In view of the application of efficient low cost lubricants, new environmental friendly and waste oils from other processes have been characterised in hot rolling conditions at the CRM laboratories. In a first phase, the lubricant is characterised using different chemical lubricant analysis, wettability trials, friction analysis and plate out trials combined with oil droplet analysis. The plate out simulator at CRM is able to spray an emulsion on a moving substrate (work roll simulation) with different spraying parameters. The effective oil quantity on the surface is

measured by a fluorescence technique to quantify the small oil film. In a second phase, the lubricants and application methods are tested on the continuous hot rolling pilot line. A stable flat rolling process is simulated on a 3 mm thick strip with a maximum width of 200 mm at a speed up to 0.5 m/s. By this almost similar roll/strip contact times are obtained as in stands one and two of an industrial finishing mill. A specific task in the evaluation has been the development of a dedicated multiple oil injection installation to apply up subsequently to four oils directly on the work roll cylinders. This allows a very quick change of oil composition without changing any other rolling or spraying parameter during the hot continuous rolling trial. In order to have the same industrial emulsion conditions, a lubrication header configuration of an industrial hot strip finishing mill is used. This allows to do a first evaluation of the lubricant and lubricant application practice in terms of their efficiency. Afterwards, the best practice technique is transferred to the industrial hot strip mill. Different green oils and waste oils have been compared to commercial hot rolling lubricants applied at different facilities. The results were very surprising: although a much lower cost (up to 5 times), green oils were with the most efficient oils in hot rolling operations. Savings up to 150 keuro/year could be made in industrial plants by applying these oils.

Blast Furnace Ironmaking / 207

Influence of sinter and pellets proportion and quality on blast furnaces operation

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Results of the analysis of physical-chemical properties of sinter and pellets are presented. It was shown that at BF transition to operation with high proportion of non-fluxed pellets in furnace charge, it is necessary to change the basic parameters of the slag mode as well as furnaces loading practice. Results of calculation for BF of OJSC "MMK" operation with high proportion of non-fluxed pellets of Sokolov Sarbai Mining Beneficiation Plant in the charge with various content of local sinter are presented. Increasing proportion of pellets in metallic burden leads to reduction in magnesia concentration in the blast-furnace slag. This is accompanied by slag viscosity increasing, reducing its ability to absorb sulfur, as well as rising of melting temperatures of metallic burden with the increase in bottom gas differential pressure and limiting ability of process intensification by hot blast. To increase the concentration of magnesium oxide in the slag at sinter production it is advisable to use the combined basic flux consisting of 70% regular and 30% dolomite limestone.

Blast Furnace Ironmaking / 208

Mathematical model and stabilization system for slag mode of blast furnace operation

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Based on in-depth investigation of blast furnace slags composition and viscosity it was found that the conditions of blast furnace synthetic and industrial slags could be characterized by slag index "a": $a = (k_1CaO + k_2MgO + k_3TiO_2) / (k_4SiO_2 + k_5Al_2O_3 + k_6FeO + k_7MnO)$. Here coefficients $k_1, k_2, k_3, k_4, k_5, k_6, k_7$ characterize known values of coulomb forces in ion structure of multi-component slags, %

The viscosity of homogeneous slag [U+F068] as a function of temperature and chemical composition could be estimated by the following formula: relationship

$$m = (Aa^2 + Ba + C) \exp(U/RT)10^{-5},$$

where m – absolute slag temperature, U – activation energy, J/mole; R – universal gas constant, J/mole; A, B, C – constant coefficient of parabolic dependence of viscosity from temperature, estimated based on experimental investigation of composition and viscosity of industrial blast furnace slags. The viscosity of heterogeneous slag could be estimated of the following formula

$$m_g = A(100-CSR)^{\bullet} m,$$

where m – fraction of fines below 3 mm in hearth's coke; CSR – coke strength after reaction, %.

The developed formulas re incorporated in a slag model which is used a apart of control and optimization system for several balst furnace of Ukraine and Russia.

Blast Furnace Ironmaking / 209

Implementation and results of non-destructive testing method for cooling staves thicknesses at NLMK

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Industrial furnaces are subject to extreme heat stress, chemical reactions and abrasive reactions. At the bosh and stack levels of blast furnaces, cooling staves are subject to severe abrasive wear. The staves if worn may cause water leaks, chilling of the furnace and/or catastrophic explosion. Thus, techniques have been developed to monitor the remaining stave thickness so that timely maintenance can be carried out. Traditionally, ultrasonic techniques (UT) cannot be used to measure the remaining stave thickness due to the multi-layer nature of the furnace, unless ultrasonic rods were preinstalled in the inlet/outlet pipes of the staves for fixed point measurements. In 2013, there was a break-through in the non-destructive testing methods for stave thicknesses. A technique known as the Low Frequency Pulsed Ultrasound (LFPU) was developed. The technique was tested on a medium size furnace on both cast iron staves and copper staves. The measurement results were verified by the conventional UT tests at designated copper rod inserts. Soon after this pilot project, there have been requests for the LFPU measurements from around the globe. This paper shows the comparison of the conventional UT tests and the advanced LFPU tests. A case study of the inspection performed at Novolipetsk MK is addressed.

Blast Furnace Ironmaking / 210

AU-E control of blast furnace refractory lining at NTMK-EVRAZ ensures intensive operation and prediction of the end of campaign of titania blast furnace.

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Intensive operation of blast furnace allows an increase in production of hot metal and profitability of Iron & Steel Works. However, blast furnace structural integrity could be sacrificed if no measures are taken to protect refractory lining and to build stable accretion. NTMK-EVRAZ is a unique and advanced blast furnace operation with titania load of about 45-50 kg TiO₂/thm. Successful operation of NTMK's blast furnaces is guaranteed by deviation of blast furnace process from thermo-dynamical equilibrium to suppress formation of titania carbides and nitrides. As a result ultra low silicon and titanium hot metal is produced. The paradox is that despite of high titania load there is no any better protection to the hearth refractories as compared to conventional blast furnace and addition of titania or shungite does bring any benefits. NTMK and Hatch developed a systematic approach to monitor conditions of BF hearth lining using Acousto Ultrasonic-Echo (AU-E) non-destructive testing developed by Hatch. Continuous and periodic inspection of blast furnaces revealed problematic areas with accelerated refractory deterioration and minimal thickness, formation of elephant foot, extent and speed of refractory wear, cracks and other anomalies. Improvement in coke quality, staves washing, control of ore load distribution, periodical slow run of the furnace etc. were recommended and implemented to prolong furnace life and predict the end of campaign while maintaining the intensity of furnace operation.

Industry 4.0 / 212

Improving operational efficiency and cost competitiveness of steel plants - A case study for electric furnace melt shop and hot rolling mill

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A methodology has been developed for improving the operational efficiency and cost competitiveness of steel plants. The salient features of this methodology which is implemented working closely with steel plant personnel, includes internal benchmarking, comparison with best practice (similar class) after normalization of key performance indicators (KPIs), fundamental process analysis including heat and mass balance as well as development of improvement roadmap. This methodology was recently applied to perform a technical review of operational efficiency and cost competitiveness of NSMMZ' EAF meltshop and rolling mill. During the improvement drive the team focused on production, technical and maintenance practices to drive down materials, energy, labour and maintenance costs. The technical review was successful in improving the overall cost competitiveness of the steel company, with an estimated savings of ~10 US\$ / t.

Sintering & Pelletizing / 216

Design and optimization of iron ore pelletizing plants based on coupled numerical simulations

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With the steady increase in computation power numerical simulations offer new possibilities for the design and optimization of industrial facilities. In the highly competitive business of iron making with rapidly increasing requirements in metallurgic plant design numerical models can be highly beneficial in the development process. In this paper a coupled approach of numerical simulations to design and optimize traveling grate pelletizing plants for iron ore is presented.

With the first numerical model the processes in the pelletizing bed were simulated. The code for the threedimensional numerical simulation was developed in Microsoft Excel's Visual Basic for Applications (VBA). The model is based on the finite volume method and includes mass, momentum, energy and species balances for gas and solid phase. The plant configuration as well as the raw material composition are fully customizable.

The second numerical simulation focusses on the induration hood of the pelletizing plant. 3D CFD studies were carried out with Ansys FLUENT. While boundary conditions such as temperature profiles and massflows were taken from the bed simulation, the CFD studies yield the firing zone temperature distribution which again can be used as input for the bed simulation.

With this coupling the accuracy of both simulations significantly increases and detailed insights in the pelletizing process are obtained which offers great opportunities for design of new plants as well as optimization of existing plants.

Keywords Pelletizing, Simulation, Plant Design, Process Optimization

Hot Strip Mill / 217

Early roll defects detection in roughing mill

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To decrease time in defect crisis solving in roughing mill in ArcelorMittal Dofasco, a very robust vision system, RollScope, has been installed in stand in front of lower roll. The RollScope developed by CRM allows to take images of roll surface using a water column to avoid vapour and waste disturbances. This water column acts so as a guide light resulting in very good quality of images of field of view width from 6 to 8mm. The difficulty to overcome was the very small available space. Two solutions have been studied: using positioning units inside the stand or using a beam placed between chokes to support the measurement head. Both these solutions will be discussed in this paper. The following of industrial campaigns and the resulting images analysis have been used to define of a procedure to optimise scheduling and process conditions to suppress the occurrence of critical roll degradation at the origin of surface defects and are described.

Applications & Galvanizing / 218

Industrial applications of reliable topography measurements

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The Surface Roughness Meter (SRM), developed by CRM and commercialised by Amepa, has been enhanced by additional waviness measurement. SRM, deployed nowadays at more than 40 installations around the world, is used in several industrial lines and interest is more and more increasing from automotive and high quality surface products manufacturers and users. These

applications, including precision and repeatability, will be described as well as the economic gains for European industry.

Blast Furnace Ironmaking / 219

Reactive PCI® technology - the next milestone in Küttner's comprehensive PCI know-how

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Grinding and drying as well as pulverized coal injection is today state-of-the-art in Küttner's product portfolio. Over decades improvements and developments have been made for the benefit of our clients. The aim was always to increase the injection rate by reducing the coke rate at the same time. Overall ironmaking cost should be reduced by keeping a predictable and safe blast furnace operation. Now, the engineers of Küttner have developed the next logical step to even more reduce finally the coke rate. Reactive PCI® allows you to replace a part of the necessary transport gas for the pulverized coal by a so-called reactive gas. Reactive, because it is taking part in the reactions with the injected pulverized coal. The mathematical model will be introduced as well as first promising results.

Electric Arc Furnace / 221

Robotic guided tap hole maintenance on EAF, a major increase of worker safety

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In metallurgical plants you will find lots of areas with dust, smoke gases and easily accessible liquid steel. To carry out manual work in this environment is very dangerous and should be avoided. Nowadays more and more manipulators and robotic solutions are used to substitute tasks in hazardous areas. One example for such a dangerous work is tap-hole-opening in electric arc furnaces.

Usually this is done by using an oxygen lance burner which is held to the tap-hole. In this case the operator has to stand directly next to the dangerous tap-hole area. Due to the weight of the lance, sometimes 2 persons have to work in the exposed area.

This paper describes the full versatile Primetals LiquiRob system and its new developed feature "tap-hole-opening for EAF". The robot is used as elongated hand of the operator. Heavier lances can be manipulated, since there are no work safety restrictions for the robot, this means, more energy for the burning process is available, which significantly increases the opening rate. While the operator stands in a safe distance, he can guide the burning lance with the robot precisely to the tap-hole. Using a CCTV system, this job can be done even from the control room. First operational results from oxygen lance operations in similar areas are presented.

Industry 4.0 / 222

Introduction of tablets for work roll evaluation

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Despite continuous progress in roll development and improved rolling conditions, the control of work roll performances remains a major concern for the hot strip mill. One shortcoming is objective information and knowledge about the roll degradation and the origin. To address this situation, several hot rolling mills introduced a work roll evaluation procedure that is performed at the end of each rolling campaign. Most commonly a classification of the possible degradation occurrences is made with a severity index. To reduce the subjectivity of the roll evaluation, a procedure and guidance booklet was developed in the frame of a European project “Mastering Rolls”, (7215-PP/066). Now, more recently, this development has been taken a step further within the European project “Intellub” (RFSR-CT-2013-0003) where a tablet application was introduced to assist with the roll evaluation. The first implementation and testing of this new technology at the mill immediately showed the improvements and innovations that are possible with the introduction of this new tool.

Cold Rolling Mill / 223

Numerical investigations of oil film thickness formation inside the roll-bite during cold rolling

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Rolling of hard and thin strips is still a challenge for steel industry. For such a configuration, the rolling force could drastically increase and might exceed the tandem mill limit. Flexible lubrication has been developed at ArcelorMittal to cope with the aforementioned issue. It enables controlling effectively the friction condition inside the roll-bite through lubrication process with suitable rolling emulsions. Two important influence factors that control the frictional force between the work rolls and the strip are the amount of lubricant inside the roll-bite as well as its viscosity. In this paper, numerical simulations of cold rolling process are performed to reveal the influences of process parameters, e.g. rolling speed, tension and strip’s flow stress, on the oil film thickness formation inside the roll-bite, thus the friction condition. Results reveal complex evolutions of oil film thickness with process parameters, especially for the Advanced High Strength Steels (AHSS). These results would enable adapting process parameters according to rolled products to maintain the feasibility and productivity.

Hot Strip Mill / 224

Characterizations, modelling and lab trials assisting the development of a graphitic HSS work roll for rear finishing stands

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For several decades, researchers did many hypotheses on the unique behaviour of ICDP in rear finishing stands. All those hypotheses will be discussed to make the clear link between the role of graphite, the mechanical and structural properties of ICDP that make this grade so unique. The aim is to highlight which properties are required to bear the specific degradation and incidents occurring in rear finishing stands. The development of new work roll grades nowadays also rely on modelling to evaluate in use stresses and optimize thermal treatments notably. Advanced modelling combined with the detailed review of the literature on ICDP lead to the development of

laboratory trials to evaluate new developed grades versus sticking and incidents in rear finishing stands. Based on modelling and simulation at laboratory scale of specific incidents, a graphitic HSS has been developed and is nowadays used in several hot strip mills throughout Europe. A detailed review of the performances of the graphitic HSS obtained in those HSM will be compared to the actual reference ICDP.

Blast Furnace Ironmaking / 225

Operation and maintenance technology for prolong campaign life of large blast furnace hearth

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Based on the investigation results of carbon brick damage of 4BF at Baosteel, this paper discussed the viewpoint that maintaining a stable solidified iron layer (protecting layer) on hot surface of carbon brick is the key for prolong campaign life of hearth and expounded the importance of ensuring higher heat transfer effect of carbon brick construction system. The paper expatiated the operation and maintaining measures to control rising hearth sidewall temperature and erosion of large size blast furnaces at Baosteel, such as improving permeability of deadman and decreasing circuiting flow density of hot metal in hearth by increasing blast energy or lower PCI operation; prolong length of the tapholes; carbon slurry grouting at taphole area, and so on.

Key words large blast furnace; hearth; solidified iron layer on the hearth sidewall; operation and maintaining measures to prolong campaign life of hearth

Rolling / 227

A training framework for i.Process/Steel-RHF APC system

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In order to optimize the conduction of steel billets reheating furnaces, advanced multivariable process control techniques are needed so as to guarantee a suitable handling of all furnace conditions. The final goal is the achievement of energy efficiency while preserving product quality: a profitable tradeoff between energy saving, environmental impact decreasing and throughput maximization has to be assured.

When implementing a new control system on a process plant, the operators' training phase can be a very crucial phase both from the system safety point of view and for the actual acceptance of the new (automatic) advanced controller by human operators. All these aspects finally affect the service factor of the i.Process/Steel-RHF Advanced Process Control (APC) system. i.Process/Steel-RHF is an advanced control tool for reheating furnaces based on an adaptive Model Predictive Control (MPC) strategy.

To maximize field performances, special efforts have been dedicated to the development, jointly to the APC system, of an ad hoc training framework that moreover could assure a significant

speed up of the operators' training phase. In this way, tedious and repeated meetings with the control system developers are avoided.

Particular effort has been put, during the APC system development, to the detection of significant process behaviors that needed particular explanation to operators for their acceptance. This concurrent engineering approach has resulted to be particularly effective in the development of the training tool.

Environmental / 229

Explosions due to the entrapment of water by molten iron, steel, or slag

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Explosions due to the entrapment of water by molten iron, steel, or slag pose a very serious safety risk in the industry, and can occur during any of the several molten stage processes involved in iron & steel making. Although prevention of these explosions is the primary objective, understanding the overpressure resulting from an explosion is important for worker protection, and to the design of control pulpits, control rooms, crane cabs, and protection of other equipment. A commonly used engineering approach to predict overpressure is to calculate the explosion pulse at the source (overpressure profile with time using a Kingery-Bulmash blast parameter model, for example), and then calculate a decreasing overpressure with radial distance thereafter. This approach, however, neglects the complex interactions of the blast wave with walls and other bodies, which can result in wave amplification leading to overpressures higher than that calculated using the simpler, one-dimensional methods. Compressible, transient, computational fluid dynamics (CFD) modeling overcomes these limitations by solving the problem in three dimensions and inherently accounting for these complex interactions. In addition, CFD also predicts the negative pressure behind the blast wave and the resulting blast wind that can also cause equipment damage and injury to worker personnel. Historically, attempts to solve these problems using CFD have been plagued by excessive simulation times. This paper presents a methodology to predict overpressure due to a molten metal-water explosion using a novel, manycore CFD code – EXN/Aero, developed by Envenio Inc. This code represents a step change in supercomputing of fast transients, rendering problems like this tractable within typical engineering design cycle timelines. This capability is illustrated through a case study, which demonstrates the suitability of the methodology for the design of structures to withstand the overpressure, the design of explosion vents or rupture disks for the relief of overpressure, and for informing best safety practices for personnel.

Cold Rolling Mill / 232

A feed-forward control for roller levelers using FE based process models and fast meta-models

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Due to the ongoing trend towards fully automated processing lines the development of process controls is highly desirable. In the field of roller leveling a process control has to ensure a constant flatness of the processed strip. A direct measurement of the remaining curvature after leveling is difficult as the strip is suspended to external forces such as gravity or tensile stresses. Therefore a feed forward control for roller leveling is proposed which is based on a force measurement within the first bending triangle. This force measurement can be directly linked to the characteristics

of the incoming strip such as the yield strength or the initial curvature. Using an FE model including a closed-loop control it is possible to determine the correct setting of the roller leveler for different strip characteristics in one simulation run. The results from the FE simulations are transferred to meta-models allowing for an online adaption of the leveling machine during the process. The concept of the proposed feed-forward process control has been successfully implemented to a down-sized roller leveler. As first results show the process control is able to ensure a constant flatness of the strip if changes in the incoming curvature occur.

Cold Rolling Mill / 233

Multi-target optimization of batch annealing bays

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The efficiency of a batch annealing bay is to a large extent dependent on which coils are combined to create the stacks. At Tata Steel IJmuiden a smart stack building algorithm is in use to optimize productivity. However, over the past few years the throughput of the batch annealing bay has become more volatile as more steel was shifted to the hot dip galvanizing lines. Especially when throughput was low this has resulted in a decrease in timely coil delivery as optimization was still done on productivity. To ensure timely delivery of delayed coils this has led to an increasing need for manual intervention in the bay scheduling. To solve this issue the optimization target of the stack building algorithm was modified, incorporating not only bay productivity but also timely coil delivery. By using the new optimization target a smarter balance between efficiency and delivery performance was obtained. This has resulted in a reduction of delayed coils from 27% to 4% of the coil population without noticeable effect on productivity. In addition, the automated response to changing conditions reduced the need for manual intervention in bay scheduling. Before implementation nearly daily intervention was necessary to ensure timely coil delivery. After implementation no manual intervention has been required for a period of 3 consecutive months.

Rolling / 234

Hot forming of a low-carbon steel AISI 1005 for fashion accessories

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In this work, the use of a low-carbon steel AISI 1005 (Wr. N. 1.0303) is proposed as a substitute of CuZn39Pb3 brass in order to produce fashion accessories by hot forming. The heating process of the billets for hot forming has been carried out at 1050°C through a single heating step inside an induction furnace or by double step inside muffle and induction furnaces. The surface quality of the components has been evaluated after hot forming process by means of a quality indicator, as well as the process repeatability has been quantitatively estimated too. The microstructural characterization has been carried out by optical and scanning electron microscopy, while the grain structure and perlite distribution have been measured by means of an image analyzer. In general, different grain size and morphology are observed throughout the component, revealing different recrystallization and growth kinetics. Fine carbide precipitation is locally revealed in the material. Defects are observed in the final parts, such as cold shuts and oxide inclusion, due to improper design of die.

Hot Strip Mill / 235

A fast model to evaluate threading refusal risk in hot rolling process

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Threading is a critical phase in hot rolling both in the finishing and the roughing mill. To avoid threading refusals which cause loss of productivity and steel yield, some constraints are applied on the process: no lubrication or only on the strip body, limitation of thickness reduction, high slab temperature at the furnace exit... However, we had no means to estimate the threading risk for each incoming strip or the needed process modification to be applied to avoid the problem. Therefore, we developed a fast analytical model of the threading phase based on power balance between friction and deformation to predict the strip speed evolution when it enters into the stand. This model has been validated with comparison with finite element simulations in the same conditions and the results between both models are in good agreement. As the computation time for the analytical model is much lower than the finite element simulation, we performed a comprehensive sensitive analysis to study the influent parameters and efficient actuators to decrease the threading refusal risk.

Blast Furnace Ironmaking / 236

GRANSHOT turns logistic challenge into valuable product in integrated steel making

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UHT has delivered and commissioned the world's largest GRANSHOT® metal granulation unit to TATA Steel's new steel plant in Kalinganagar, Odisha. The delivery enables a seamless industrial route for excess blast furnace iron with a granulation capacity of 300 ton/h. The GRANSHOT® unit is engineered for tapping directly from the torpedo to enable easy metal transfer between the blast furnace and the granulation site. This has provided better internal logistics during start-up of the blast furnace and steel plant by allowing independent operation of the two units. The granulated pig iron, GPI®, marketed by TATA as Ferrosshots have been very well received by the users. The granulated product is very suitable for use in steelmaking operations such as the electric arc furnace and basic oxygen furnace as well as in foundries as a replacement of DRI and scrap. This paper will present the GRANSHOT® plant at TATA KPO, discuss operational experiences and the usability of the granulated product at the final customers.

Surface Technologies / 237

Process parameters for the production of steel roll-bonded multilayer plates and strips

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In the past decades, all possible strengthening mechanisms have been fully exploited to tailor the mechanical properties of steels. Nowadays, it is becoming difficult to move further and meet the continuously increasing properties requirements, as the physical limits have been almost reached in bulk metals. Multilayer metallic materials produced by roll-bonding can be a viable solution to combine “contradictory” properties (i.e. strength and energy absorption, abrasion resistance and toughness, etc.) in one single product.

This paper describes the process parameters (surface preparation, interlayer coating, joining techniques and rolling schedule) to produce roll-bonded clad plates and strip. Three point bend testing proves that sound metallurgical bonding is obtained after hot-rolling at 1100 °C of steel multilayer-packs assembled by welding, whatever the steel chemistry and the rolling schedule applied. No abnormal inclusion density is found at layer interface. However, surface flatness is shown to be a fundamental requirement to build-up the packs prior to roll-bonding.

ELC roll-bonded plates with different types of hard outside layers (pearlitic or, after accelerated cooling, martensitic) as well as hard plates with soft ELC outside layers were successfully produced at lab-scale. Countless others layers combinations can be developed for both strip and plates applications, free from thermodynamics and chemistry constraints.

Hot Plate Mill / 238

Flatness characterisation of hot plates for plate levelling

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Flatness is an essential property for the quality of heavy plates. To achieve the flatness required by the customer, levelling machines are used for many types of plates. Today, flatness is described by means of the deviation of the plate topography from a 1 or 2 m ruler according to DIN EN 10029. This measurement method does not provide any further information about the type of flatness defects. The commonly known value I-unit is used to determine unwindable flatness defects such as centre buckles or edge waves but does not provide information about windable flatness defects. In this work, a new method is presented to determine and quantify both windable and unwindable flatness defects as well as ski defects by means of characteristic values before levelling. The characteristic values are received from online measurements of the flatness gauge. Applying this characterisation method to real plates shows that the determined values are suitable for the characterisation of flatness defects of hot rolled plates. The data of type and magnitude of the flatness defects can be used to determine machine settings and strategies in hot plate levelling.

Industry 4.0 / 239

Newly developed combined abrasive cut-off and cold circular sawing machines for flexible applications in the steel and special metals industry

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Semi-finished steel and Special alloy products need to be cut for further processing. In most cases (e. g. for cold cutting of bright bars, etc.), shortest-possible cutting cycles, precise and clean cuts are a must. 2 cutting technologies, abrasive cutting and cold circular sawing, meet these requirements. For certain material grades, however, cold circular sawing is the more economic solution whereas other materials require abrasive cutting. Because of the very opposite requirements on the cutting machine, it was very difficult in the past to combine both cutting

technologies in one unit. Therefore, steel producers or distributors with diversified product mixes were forced to decide if they should invest in an abrasive cut-off machine, a cold circular saw - or to buy both types of cutting machines. BRAUN's newly developed combined abrasive cut-off and cold circular sawing machine does now solve this dilemma. Depending on the product to be cut, this novel high-performance cutting machine allows to optionally use both cutting technologies. BRAUN's machine design also allows to hange quickly from abrasive cutting mode to cold circular sawing mode and vice versa. The paper describes the key features and the advantages of this new combination machine, as well as operational results.

Electric Arc Furnace / 242

Behaviour of Cs and Sr radionuclides during the electric arc re-melting of contaminated scraps

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The recycling and treatment of radioactively contaminated scraps, mostly from the nuclear industry, are becoming more and more prominent issues facing the iron and steel sector. A proposed treatment route of steel containing radionuclides is with the Electric Arc Furnace (EAF). However, a deep understanding of the behavior of radionuclides (mostly cesium and strontium) during arc melting has to be established, so as to ensure both the cleanliness of the final steel, appropriate handling of radioactive slag/off-gas, and the safety of plant personnel.

In the present study, thermodynamic equilibrium distribution of Cs and Sr between molten metal, slag and gas phases under the EAF process conditions were evaluated. Critical evaluation and optimization of the thermodynamic properties of Cs and Sr in molten Fe and slag were conducted, based on existing literature data.

Blast Furnace Ironmaking / 246

Hot blast superheating – A scalable technology to reduce coke consumption

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The concept and benefits of retrofitting a cold blast mixer with plasma torches to heat hot blast air will be described. A 'hot mixer' would top-up hot blast temperatures achieved during the stove firing cycle and eliminate the need for cold blast air mixing. The technology is scalable; implementation of just a few plasma torches will reduce coke consumption and GHG emissions. Candidate general arrangements for the 'hot mixer' in the hot blast main will be described as well as potential modifications to plasma torches for blast furnace service and strategies to service plasma torch units. Pre-conditions and preparations for a field trial will be described.

Rolled Properties and Characterizations / 247

Hot work tool steels strengthened by carbides and inter-metallic phases

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Hot work tool steels have been developed, employing combined precipitation of carbides and intermetallic particles. Synergistic precipitation hardening effects were used to reduce the necessary carbide content. An appropriate minimum of nickel and aluminium additions were determined to precipitate intermetallic NiAl particles, maintaining the materials characteristics. Material and technological properties on tempering behavior, impact toughness, isothermal tempering resistance and thermal conductivity were evaluated. Microstructure analysis using transmission electron microscopy (TEM) reveals the existence of NiAl-rich particles in the overaged condition. Atom probe tomography (APT) proof the coexistence of nm-sized NiAl particles and Mo-rich carbides in the quenched and tempered state. First results on thermal-shock resistance of homogenized industrial material are promising. Overall, attractive material properties, combined with resource efficiency and low costs were obtained by the use of intermetallic NiAl particles, compensating carbide forming elements.

Secondary Metallurgy / 248

Improving the ingot quality by understanding the behavior of the mold flux during casting process using a 3D fluid/structure numerical simulation model

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It is well known now that the ingot defects like hot tears or cracks are rooted at the first beginning of the solid shell birth. Damages result from the competition between hydrostatic pressure within the turbulent flow of the liquid zone and the solidifying skin under tensile stresses and strains state. In addition, the thermal energy extracted from the cast product by the mold has huge impact of the thickness of the shell. It depends on the air gap growth issued from the shrinkage of the solidifying metal together with the deformation of the mold components. In addition, within the pouring phase, the mold flux can be inserted between mold and ingot shell that is also impacting the heat exchanges. Numerically speaking, the method able at taking all that phenomena into account through an accurate way is a fluid/structure model. Indeed, a standard CFD method does not represent the solid behavior, so that the stresses, strains, air gap evolution due to the shrinkage of the shell are not reachable. In this paper, a new 3D fluid/structure model involving the turbulent fluid flow and the solid constitutive equation is described. The management of the dedicated “liquid time step” allowing high velocity motion into the liquid phase of the alloy coupled with the “solid time step” dealing with the solid phase and the corresponding slow motion, is presented. The model considers as well added bags of mold flux on top of ingot surface impacting not only the heat exchanges with ambient but also with mold during casting process. An application on an ingot casting process taking into account the coupling with the deformation of the mold is presented. Moreover, based on that model, it is shown that the segregation within the ingot is tracked. In addition, the top powder is accounted as deformable body following the shrinkage of the top surface of the ingot. The exothermic reaction is considered as well in order to estimate its impact on the cooling time and the final quality of the cast product.

Refractories Steelmaking / 249

Introduction of a 3D-laserprofile-measurement-system that is immersed in to a hot steel casting ladle to measure and evaluate the entire conditions of the refractory lining including optimization of lining and ladle treatment, gap and

crack detection, lining surface temperature and automated sand filling of the ladle-taphole.

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The new developed “LaCam Explorer” measuring system shows a unique way to measure refractory lining thickness and 3D-profile in hot steel casting ladles **from inside** the ladle. The Laser-measuring system has an innovative, yet simple and rugged design that allows immersion of a laser head into a hot Steel Casting Ladle with surrounding temperatures of more than 1100 °C and surface temperatures up to 1700°C. The system’s laser-beam rapidly scans the lining thickness of the entire surface, collecting millions of data points that are generated in a wide range of computer displays from simple tabular reporting to a virtual walk-through of configurable 3D images. By means of precise determination of the taphole-geometry an automated sand filling of the tap hole can be made additionally. This new development allows steel makers to measure refractory-lining thickness in Steel casting ladles in less than three minutes, This measuring system can provide steel makers with improved safety, increased ladle availability and capacity, extended refractory life and cost savings in energy, material and the maintenance of hot Steel Casting Ladles.

Advanced Rolling / 250

Concept, reference and performance of the CEM® technology

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Since the end of the 1980s, thin slab casting and rolling plants, in particular CSP® plants are well established for the production of hot strip. By introducing the endless operation mode, a new generation of casting and rolling plants was created. CEM®, the compact endless casting and rolling mill, is the innovative solution introduced to the market by the Korean steelmaker POSCO and the SMS group. CEM® is a highly flexible concept that benefits from the advantages of both the batch and endless operation mode. This enlarges the product mix by ultra-thin gauge rolling with strip thicknesses of down to 0.8 mm and ensures a highly efficient operation at a low cost level. Furthermore, the joint approach combines SMS’ engineering and process experience with the production and operational excellence of POSCO. Beside the applied technology in a CEM® plant according to the latest reference, the paper will illustrate the performance of the concept for the production of commodity and advanced high strength steels using theoretical analyses and practical operational results.

Cold Rolling Mill / 252

Severstal’s revamp of their four stand flat cold tandem line in Cherepovets

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In 2014, SMS group received the order to modernize Severstal’s fifty years old four stand tandem mill (TCM) in Cherepovets. Main aims are to increase the capacity and strip quality as well

as to prepare the mill for a later coupling to a new pickling line (PL). Additionally reduced off-gauge length, raised availability and increased automation rate are required to improve the yield. In a follow up to previous papers, this presentation demonstrates the project from the initial situation, the design, the shut-down, the start-up and the achieved benefits from Severstal's point of view. The main subjects of the revamp project are stronger mill stands #1 - #4 with a new AC drive system at the 1st mill stand, full automatic roll change devices and a reduction of the gap time between two coils. New actuators are implemented in the mill stands (hydraulic adjusting systems, work roll bending, CVC® plus shifting), along with 2 SMS X-Shape® measurements. Furthermore a new field excitation control of the existing DC drives (Ward Leonard drive trains) and the new drive of mill stand #1 improve the mill's dynamic behavior. Advanced thickness and speed/tension control along with integrated flatness control achieve excellent geometrical product quality. A model-based L2 setup system provides reliable parameters for an extended product range; it also enables the threading assistant function to ensure automatic strip threading with minimum off-gauge length. State-of-the-art automation functions ensure smooth rolling and reliable product quality on the highest level. The paper will demonstrate the most interesting technical aspects of mechanics and automation, the challenges of project execution including shut down, and how they were managed by joint efforts of Severstal and SMS group. The achieved production and quality results as part of Severstal's prime flat steel production are presented, proving the business impact of Severstal's investment.

Cold Rolling Mill / 253

X-Shape – high precision and cost-efficient flatness measurement and control

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Ten years back SMS group has launched its X-Shape flatness measurement system for cold rolling mills. The core component of X-Shape is the flatness measuring roll developed by SMS group. Its outer appearance can hardly be distinguished from a conventional deflector roll, but it is the sophisticated technology inside that makes the difference.

Main features are - state-of-the-art, four-hole measuring roll, - the roll surface remains closed, measurement without leaving any marks on the material surface, - maintenance-free signal and power transmission technology, - measuring width up to 3,000 millimeters with a maximum of 96 sensors, - model-based raw signal evaluation.

The consistent development of the robust, low-maintenance, and cost-efficient X-Shape system led to a high precision flatness measurement and control.

Since 2009, SMS group has delivered more than 50 X-Shape measuring rolls to customers around the world. Operational results from various cold rolling mills will be displayed as well as further developments driven by this broad experience, e.g. X-shape flatness measurement for hot rolling mills.

The X-Shape system is an integral part of the X-Pact® electrics and automation for cold and aluminum rolling mills supplied by SMS group. X-Shape can be installed in new plants or can easily be retrofitted in existing facilities. Furthermore X-Shape measurement and control has been provided as technology package for improving strip flatness in existing cold rolling mills.

Industry 4.0 / 257

PQA-the success factor to reach next performance level in hot and cold rolling

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Key words: Process, product, performance, optimization, quality management, expert know how, automation, digitisation,

A competitive landscape pressurizes the steel producers business, zero defect requirements from customers forces the producers for additional efforts in process control and quality management. The so called quality related cost, which include also rework, cost for downgrading or even scabbing of material is already a remarkable lever in a plants profitability breakdown. The introduction of advanced state of the art grades in the product portfolio requires already a budgeting for the expenses for R&D and quality management.

PQA has been developed as a process and quality management software solution next to existing level 2 or level 3 automation systems. It is focusing on the analysis of process data, equipment information, in line quality measurement devices and trend analysis to obtain an answer whether the process is according to definition and expectation and whether the intermediate or final product can be shipped for further processing as prime material.

Advanced analytics which are linked to an expert know how based configuration identifies deficiencies in the production and processing process. An intelligent, state of the art rating system evaluate tolerable deviations.

PQA comprises the software platform including the database, data configurator and collector from the different sources in the production process and units. The core element of the platform is the knowledge based expert know how package defining process and quality defining fundamentals. The paper describes the structure of the software package, it gives insights on the expert know how package, process and quality evaluation and points out the customer benefits, cost reduction, improvement yield, customer satisfaction increase.

The link to recent operational references is given.

Byproducts / 259

Utilization of olefin plants waste coke as carbon additive in steel making

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During production of ethylene, propylene and butadiene at SABIC olefin plants, coke is deposited on furnace tubes. Deposited coke layer increases with time which reduces furnace efficiency. Hence, removal of coke through de-coking process-stage is frequently required followed by landfilling of collected waste coke. Moreover, HADEED imports carboneous additives or recarburizers to be added during steel making process. A study was conducted to evaluate potential utilization of wasted coke from SABIC petro-chemical plants as recarburizers. Compositional analysis using carbon/sulfur analyzer and XRF revealed high fixed carbon in olefins coke ranging between 80% to 95% and low sulfur content of less than 0.5%, which meets steel making requirement. Moreover, 50 plant trials were conducted using coke from different olefin plants, where coke was added during Electric Arc Furnace (EAF) tapping and during ladle furnace treatment. Average carbon recovery of these trials was high reaching to more than 90%. Due to these successful trials, coke was re-classified from waste to recyclable by-product and olefins' coke batches is used continuously in steel making. This supports sustainability and reduces carbon additives cost at HADEED.

Blast Furnace Ironmaking / 262

A combined data processing approach to improve blast furnace raceway blockage detection

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To achieve minimal coke rates in blast furnace operation it is crucial to obtain optimal burning of additional fuels like e.g. pulverized coal (PC). However, there are operating conditions, where an optimal burning is not possible and it is beneficial to shut down the PC supply on one or more injection lances. The frequent case of raceway blockages can lead to reduced wind throughput on the effected tuyere. If PC is injected in that tuyere the unburned coal might lead to locally reduced permeability of the burden. Thus it is necessary to have reliable information of the current raceway condition to be able to shut down PCI lances if beneficial and to do so with short latency.

This study aims to find an optimal blockage detection based on the combination of hot blast flow rates and additional tuyere cameras. A usual implementation of triggering the shutdown of PCI lances is to use a threshold value for a minimum wind flow rate through the individual tuyere sections. However, a blast furnace never shows exact axially symmetric behavior, thus the hot blast flow rates vary between the tuyeres. So applying the same threshold level to all tuyeres is not an optimal solution to trigger the shutdown of PCI lances. Thus, we tested various approaches for the signal processing of hot wind data. To allow an efficient testing of various algorithms and parameter sets a modular software test bench was implemented in Matlab/Octave. To assess the results of signal processing, it is also necessary to visually check the raceway conditions. For this we collected image data on various tuyeres. As the flow rate data needs to be tested over many hours of plant data, also the tuyere images need to cover these time spans. Hence, we have thousands of raceway images, which cannot be checked manually for blockage assessment. This inherently leads to the need of fully automated image processing to detect blockages from the raceway images. The software test-bench was therefore extended to allow also the testing of image processing algorithms. This additional effort does pay off in a way that also combined methods of using available plant data of the hot blast flow rates plus the optical information of tuyere cameras can be evaluated for an optimal implementation in the blast furnace process control system.

Electric Arc Furnace / 264

Power system analysis of direct current electric arc furnaces - SGL PRO ARC DC

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Cost competitiveness and productivity management achieved safely and meeting high quality standards are paramount to the success of steelmaking in the current market. In recent years, a tool to perform three phase power system analysis of alternating current electric arc furnaces – SGL PRO ARC – was developed and successfully deployed to optimize mast control systems and electrical operating points, benefiting dozens of melt shops worldwide. This paper will describe new features that were developed in order to better service customers operating direct current furnaces – SGL PRO ARC DC – and how its measurement and monitoring capabilities can assist melt shops in achieving their goals.

New Ironmaking Technologies / 266

Research on injection of COG in middle-upper part of COREX melter gasifier

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Coke oven gas (COG), as a kind of high heat value source, was projected to be injected into free board of the COREX melter gasifier. In this paper, a static model had been created based on mass and heat balances. The model was capable of calculating the temperature of free board, the quantity of COG injected and top gas. The results showed that the COG injection into free board can adjust its temperature efficiently. The quantity of COG burned ranged 3 Nm³/t to 20 Nm³/t when temperature is lower than 1323 K and the quantity of COG decomposed ranged 3 Nm³/t to 65 Nm³/t COG when temperature is higher than 1323 K. A maximum of 117.20 Nm³/t COG could be injected through nozzles to provide enough top gas for shaft furnace. Therefore, the maximum of the total COG quantity injected is about 132 Nm³/t; the minimum is 20 Nm³/t.

Secondary Metallurgy / 267

Automation of hot metal pouring in our steel plant

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In the Tata Steel IJmuiden BOS plant (Netherlands) the Hot Metal pouring process is completely automated. After the connection of the torpedo above the HM pit by the loco driver all movements of torpedo's and transfer cars are done by computers. Interlocks with loading cranes, avoid overfilling Hot Metal ladles, damaging the torpedo tracks and recognition of the torpedo number are guarded by redundant measurements or camera systems. The control of this process is integrated in the Desulph operator job. The article and the presentation will give an overview which measurements and tools we used during this long process of automation.

Cokemaking / 270

The modernization of a coking plant making use of "STATE-OF-THE-ART" technologies: A european case

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In the context of the reconstruction and modernization of Arcelor Mittal coking plant at Gijon works, Paul Wurth has been awarded with the engineering, supply of key equipment as well as erection and commissioning supervision services for the rebuild of two coke oven batteries and the modernisation of the adjacent by-product and relevant waste water treatment plants.

In particular, for the coke oven batteries, featuring 45 ovens each and designed to produce 1.1 million tons of coke per year, Paul Wurth will supply the refractory material and assume the battery heating-up services.

For the by-product plants, including coke oven gas desulphurization, Paul Wurth will be in charge of the overall engineering and supply of key equipment and the turnkey installation of a Claus plant for sulfur removal and a strong water plant.

The paper will highlight Best Available Techniques (BAT) adopted by Paul Wurth which will ensure compliance with the strictest environmental requirements.

Keywords: Coke oven battery design; Emissions; Coke oven gas treatment design; waste water treatment design.

Energy Management & Recovery / 271**Energy balance of the integrated route****Author(s):** Mr. SPRECHER, Marten¹**Co-author(s):** Dr. REICHEL, Jens²; Mr. BALDERMANN, Matthias³; Mr. DOMELS, Hans-Peter²¹ *Steel Institute VDEh*² *thyssenkrupp Steel Europe*³ *Hüttenwerke Krupp Mannesmann***Corresponding Author(s):** marten.sprecher@vdeh.de

"Energy efficiency" is of great importance at the present time. But first of all, there are too many numbers and figures in the issue of energy efficiency in steel production. Usually there are many differences between the theoretical, technical or even weighted values. For the Steel industry it is important to identify areas of action and to establish the link to the policy framework on the basis of these values. There are still potentials existing particularly in the field of using waste heat to improve efficiency. But this have to be addressed together with technical developments and political conditions.

Environmental / 272**Improvement of environmental protection and energy savings by suitable material handling systems**Mr. BERTLING, Rainer¹¹ *AUMUND Fördertechnik GmbH***Corresponding Author(s):** lambrix@aumund-holding.nl

Today, one of the main goals in optimization of the iron and steel making processes is the consideration of environmental protection and energy saving in every plant area. Not only the processing from iron ore, reducing agents and additives has to be taken into consideration but also the handling and conveying of the materials between the different process steps. This paper provides some sustainable solutions for the iron and steel industry. For example, the application of closed raw material yards in form of silos or enclosed stockpiles requires suitable compact stacking and extracting Systems. The use of large size silo systems allows a significantly increased storage volume on the same footprint as a conventional stockpile. Each silo can be used for different material qualities and with the use of the AUMUND rotary discharge machines travelling underneath the silos, every required blend can be extracted by requirement. Such closed storage and material extraction solution suppresses any dust development. No special dust control, no risk of material losses and no fugitive dust pollution or ground water pollution can occur. Another example is the transport of hot sinter from the sinter crusher to the sinter cooler. The wide-spread application of vibrating feeders leads to the generation of fines due to the vibration movement besides the resulting maintenance requirements. With the use of the AUMUND high temperature resistant pan conveyors no additional fines are being generated as there is no relative movement between the conveyor and the hot sinter meanwhile significantly reducing equipment wear. A significant contribution to energy savings effect is the thermally insulated transport of Hot DRI in a non-oxidizing inert atmosphere. Today hot charging is expected by customers operating a DR-Shaft Furnace-EAF route. Practically all new plants are equipped with this feature. Older Plant configurations are being examined for hot charging upgrades. Energy savings up to 120 kW/t liquid steel can be achieved, Tap-to-Tap cycles will be drastically reduced and productivity of EAF increased up to 20 %. In case HBI producing routes are being used new HBI cooling methods have been developed and patented using water mist as a cooling media thus achieving smooth cooling of the HBI resulting in stable product quality and final Temperatures below 100 degrees C for optimum downstream handling and storing.

Surface Technologies / 273**Performance supervision of automatic surface inspection systems**

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For flat steel production, the surface quality and the knowledge of surface defects is crucial to deliver a high quality product to the customer. Therefore, since end of 1990th as the first commercial systems came up, automatic surface inspection systems (ASIS) have been established as tightly integrated tool for surface quality supervision and the data provided by the systems are now more than ever basis for quality decisions as these systems provide objective online recognition and documentation of surface defects on a 24/7-base.

However, even today no one in the world can precisely quantify ASIS performance for the whole running production as in contrast to common measuring systems where the accuracy of the measurement is well-defined, it is almost impossible for the user to determine comparable quantities for an ASIS.

In the European RFCS project “CHECKSIS” methods are developed to enable the automatic verification of the performance of a Surface Inspection System. For this purpose, two approaches of external ASIS supervision are followed: periodical application of well-defined artificial defects for automatic system accuracy check and online synchronization with preceding ASIS results for instant verification of ASIS classification results.

This project is a collaboration between BFI (coordinator), tkSE, voestalpine, tkPS and Tata Steel. In the presentation the need and aim of this development, first results and further progress will be discussed.

Industry 4.0 / 274

How-to optimize steel quality by applying Industry 4.0 techniques in real-world practical examples

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European steel is decisively driven by product quality and customer demand. Industry 4.0 is yet a blurry term, nowadays being praised for bringing disruptive advantages for modern manufacturing industries in the next decades. Many people are overwhelmed by the diversity invoked by the word Industry 4.0 and although many applications are emerging, practical examples are rarely described or shown in technical detail. This paper presents clear examples focusing on product quality. For keeping their competitive edge, steel producers are longing for methods to ensure a successful production that satisfies the customer and provide substantial economic benefits for the producer. A smooth and unobstructed production process chain is therefore a common goal and obligatory precondition for high product quality. Different Industry 4.0 techniques are shown to optimize the quality of steel products. The talk gives clear advice to producers how to actually put Industry 4.0 concepts into real-world application, demonstrating a series of steel-industry proven, modular solutions that exploit newest technologies and which achieve increased economic performance. Practical examples consider the production of flat-steel products, focusing onto the process chain from re-heating furnace hot rolling mill and the pickling line. Here, the discussed technologies

are demonstrated, highlighting the practical aspects and new advantages: Re-adaption of the process chain to cope with surprising issues, prediction of deficiencies and strategies for optimizing according aggregates.

Industry 4.0 / 275

The BFI-I4.0 solution modules for fully exploiting the digitization efforts of the European steel industry

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The European steel industry identified digitization as a key enabling technology not only for maintaining its world-wide leading role with respect to product quality, but also for pushing the limits and raising efficiency, reliability and quality to a next level. Recently, many steel companies updated and overhauled existing infrastructures and prepared for being “BigData-ready” and to apply “Industry 4.0” concepts. Yet, the practical work to gain benefits from the new technologies is far from being easy. Some key questions that now struggle many vendors are: How can those new technologies be applied in their current situation? How can different processes interact to make products even better? or What has to be done to achieve economic benefits from using the new digital resources? In this paper, BFI would like to provide answers for that questions: throughout several successful research projects and in strong cooperation with its partners, it developed solution strategies that range from a straightforward utilization of Big Data, to even integrating Industry 4.0 within legacy IT infrastructures. Consequently, the paper summarizes these activities and introduces a series of solution modules on how to practically apply recent advancements like Big Data technology, semantics, distributed computing and decentral optimization. The work concludes with estimates on the potential impact and advice, how the solutions can be strategically integrated in your plant.

Rolling / 276

Economic impact maximization and throughput increase by decentral self-optimization of a pickling line

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Pickling lines are often considered as a bottleneck of steel production. Increasing the throughput has been the declared goal of many research projects. Yet, high quality pickling results depend on a complicated mixture of constraints like careful choice of pickling speed, suited entry temperature and a good estimate about how many scale resides on the strip surface. In this paper, a technique is shown that induces a self-optimization of the pickling line. Virtual coils, programmatic representation of the real products, store their production history, predict the amount of scale on the surface and propose an optimum pickling speed. Information from the surface inspection systems are introduced to effectively control the pickling process as such. The paper also shows how such a system works in a real-world production environment.

Sintering & Pelletizing / 277

Technology for improvement sinter productivity and sinter strength in the sintering process by gas fuel and oxygen

injection technology [U+2015]Development of gas fuel and oxygen injection technology in iron ore sintering

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JFE Steel Corporation developed a technology (“Super-SINTERTM OXY”) for injection of hydrogen-based gas fuel and oxygen in sintering machines, which makes it possible to greatly increase sinter productivity and sinter strength in the sintering process, and successfully applied this technology to a commercial sinter plant. [U+3000]In ordinary sintering process, after coke breeze is mixed with iron ore and limestone, raw materials are charged and sintered in sintering machine. To produce high strength and high reducibility sintered ore, it is necessary to keep the sintering temperature between 1,200 degrees and 1,400 degrees during sintering. In the temperature zone below 1,200 degrees, the strength of sintered ore decreases because raw materials don’t melt enough. In the temperature zone over 1,400 degrees, the strength and reducibility decrease by increasing glassy silicate. [U+3000]With injection of hydrogen-based gas fuel technology, it is possible to extend the period in the optimum temperature by injecting a hydrogen-based gas fuel from the upper side of the charged raw materials as a partial substitute for coke breeze. As the result, the energy efficiency of the sintering process is greatly improved, and it has been achieved to reduce CO₂ emissions. Moreover, combined injection technology of hydrogen-based gas fuel and oxygen is developing as the improvement technology of Super-SINTERTM OXY. This technology can extend the period in the optimum temperature extends longer than Super-SINTERTM OXY and increase sintering speed by increase of combustion rate of hydrogen-based gas and coke breeze by oxygen enrichment. As the results, sinter productivity was improved greatly. Then combined injection technology of hydrogen-based gas fuel and oxygen was developed and applied successfully to sintering machine at Kurashiki No. 4 sinter plant in JFE Steel Corporation. This technology enables to produce high strength sinter by changing the heating/cooling rate in the sintering process.

Gas Cleaning / 278

Information on carcinogenic substances in steel casting ladles

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In the past decades, the requirements in respect of environmental protection and the regulations by the environmental protection authorities, respectively have become ever stricter worldwide. And the possibilities to prove and measure harmful substances have been improved significantly. Moreover, the harmful effects on health of many substances have been evaluated and detected only in the past decades. Consequently, ever stricter limit values for suspect substances or substances whose harmful effect was proven are set. In all areas where high temperatures are used, there is the increased possibility that substances are released which are still bonded or remain bonded in the lower temperature range. Therefore, the ever increasing environmental regulations require technical solutions especially in the high-temperature range to be able to meet the limit values at all.

MAPEKO, therefore, developed a direct thermal combustion process and had it patented to collect and burn hazardous gases forming during the dry process. Thanks to this technology, the applicable requirements in respect of environmental protection can be met and a better working environment can be created.

We will show the results after installation of a post-combustion system based on emission measurement results and protocols of two independent measuring institutes (“Dekra” and the “Federal Agency for Control of Environmental Pollution and Healthcare” in Russia)

As a result it is ascertained that the use of a “direct post-combustion system” is suitable to meet the required limit values of the environmental protection authorities and to minimize the risks for staff and environment.

New Ironmaking Technologies / 280

Enhancing performance of integrated steel plant by combining FINEX® and blast furnace

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Rising energy demand and steadily decreasing quality of raw materials due to the global resource depletion are great challenges to the steel production today. The FINEX® Process has been developed jointly by POSCO, Korea and PRIMETALS Technologies Austria, to provide the iron making sector with the capability to lower hot metal production costs, environmental pollutions and to increase the flexibility in terms of operation and the choice of raw materials.

FINEX® is a new technology combining a gas-based reduction in a series of fluidized bed reactors and a reduction smelting in a melter gasifier. The innovative process concept of FINEX® produces hot metal identical to the blast furnace route, however without coke oven and sintering plant. Commenced in April 2007, the first 1.5 mtpa commercial plant has demonstrated the competitiveness as an alternative iron making route. Another 2.0 mtpa third generation FINEX® (3G) plant was installed at POSCO, Pohang Works and has been operating satisfactorily since its blow-in in January 2014.

Based on the well-proven plant concept, new process features, the highly competitive production costs and environmental advantages, the FINEX® Process is a proven alternative to Blast Furnace. It can also be integrated into an existing plant having a Blast Furnace and enhance performance by synergies arising from Finex and Blast Furnace.

Sintering & Pelletizing / 281

Investigating the oxidation kinetics of magnetite pellet

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Induration of magnetite pellet is a complex physicochemical process involving oxidation, sintering and the heat transfer phenomena. Often, these phenomena happen simultaneously and influence each other while being exposed to high temperature in the induration furnace, which might result in the formation of duplex structure within the pellet having the core of magnetite and shell of oxidized magnetite (hematite). The duplex structure inside the pellet might generate structural stresses because of the difference in their crystallographic and thermal properties which may cause detrimental effects to the quality of pellets for further processing in iron making furnaces. In order to achieve good quality pellets, it is necessary to study the kinetics of each of these phenomena in isolation to have thorough understanding, identify and control the responsible process parameters during induration. In subsequent to the investigation of sintering kinetics of magnetite pellets

from LKAB, this study focuses on estimating their oxidation kinetics. The reaction mechanism for oxidation of magnetite pellets and their kinetics is dependent primarily on factors such as temperature, particle size, oxygen content of the gas, etc. The isothermal oxidation kinetics considering these factors has been estimated experimentally at the pellet as well as particle scale using Thermo Gravimetric Analysis (TGA). It is found that the oxidation of magnetite pellets proceeds with two or more distinct dominant mechanisms varying with the extent of reaction. The deduced kinetic parameters will further be used to develop a mathematical model to predict the oxidation behavior of magnetite pellet during induration.

Rolling / 283

Muffle tubes: choose the right material for longer service life

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Muffle furnaces are most often used in wire drawing mills. In most cases, protective gas(es) is fed into the muffle tube. This shielding gas can be hydrogen, nitrogen, cracked ammonia or endogas. Some of these gases are very aggressive and will shorten the life of the muffle tubes significantly. In the annealing furnaces, the temperature is usually between 800 and 1,120°C. These aggressive conditions often result in a short service life. As the value of lost production is high, the decision to select a better grade (tube material) will have significant economic return.

Blast Furnace Ironmaking / 284

Improved production efficiency with material selection for steel making

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Pulverized coal injection (PCI) and natural gas (NG) injection at the blast furnace are used to inject fuel into the reaction to maintain temperature control and chemistry of the charge. The reliability of the lances to perform repeatable and be retracted for ease of maintenance is critical for production efficiency at the blast furnace. Upgrading from 300 series lance to a more highly alloyed material with rare earth elements improves service life. Additionally, a case study to be presented with material selection improving heat recovery at a steel mill with upgraded metallurgy in recuperators.

Oxygen Steelmaking / 286

Analysis of geometrical aspects of BOF converters and correlations with process parameters

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The continuous increase of the production steel in the last decades, caused the adjusted in steel plants in adapt in the new demand the acquiring manufactured steel. This study aimed to analyze the reactors ranging 6-350 tons of steel cast correlated their dimensional parameters and with

the help of the tool data extrapolation, to propose the furnace of 800 tons. Ultimately, were checked the correlation between the important aspects as, height of boom, e slenderness ratio relation and charge/volume relation. The results show the large dimensional variation between the reactors. In some cases even with similar capabilities, the reactors are different due different manufacturers. In specific cases, the reactors have a tendency to get ideality (specific volume equal 1) or overcome with it the dimensionless level tends to decrease. The proposer reactor presented the good dimensioning and having a sharp increase in global steel demand, could be studied and implemented in the future.

Key-words: BOF; Reactors; Slenderness ratio relation; Correlations.

Oxygen Steelmaking / 287

Application of the similarity method for cold modeling a 330 tons BOF converter in laboratory

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Noticed the strong national and international industrial activity, more specifically concerning the steel production and the model of oxygen converter adopted on the different types of primary refining process, this work applies to relevant models, reevaluating since the more rudimentary techniques till the current technologies. Then they will present the methods in which resulted the study of similarity in a converter 330 tons bringing to a 1/10 scale, allowing the realization of the studies in laboratory. Right after, will be performed an analysis comparison between simulation cold versus hot showing the benefits and drawbacks in working with the two situations. Ultimately, intends to show the deferens costs in carrying out a simulation to cold and hot simulation and also present the benefits to perform simulation in the cold model. The results obtained after the stage of discussion were satisfactory, since it allowed to reach plausible conclusions which will be of great value to companies that have the need for process improvement at low cost and without taking big risks.

Keywords: BOF; modeling; Cold tests; Similarity.

Blast Furnace Ironmaking / 288

Evaluation of bio-coke strength and reactivity for blast furnace use

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The use of biomass in metallurgical coke production has been identified as one of the main possibilities to introduce a renewable carbon source to the process chain of blast furnace based steel production, thereby decreasing the CO₂ emissions produced by the steel industry. In this study, multiple grades of bio-cokes are prepared by combining charcoal produced from pine chips at a high temperature (600 oC) with a high fluidity coking coal. The objective of this study is to investigate how the proportion of charcoal and the selected particle size of charcoal

affect the strength and reactivity of bio-coke. The preparation of bio-cokes and reference cokes is performed in a laboratory-scale coking battery up to a final temperature of 1200 °C. The compressive strength of the coke grades is measured both at room temperature and at an elevated temperature simulating the lower blast furnace with a Gleeble 3800 thermomechanical simulator. Chemical reactivity of the coke grades is measured both in isothermal and dynamic conditions. The reactivity tests are performed in simulated blast furnace shaft conditions including all the relevant gases (CO, CO₂, H₂, H₂O, N₂) in realistic ratios. The results of this study provide new value to the current knowledge base of possible bio-coke utilization in the blast furnace, specifically on the effects of charcoal on cold and hot strength, chemical reactivity and the threshold temperature of coke gasification when the proportion of charcoal in the coking blend is in the range of 0–10 wt%.

Oxygen Steelmaking / 289

Continuous improvements in BOF at Arcelor Mittal João Monlevade by technology slagless lance

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In this hard days for Brazil steel market, all steel shops want to achieve the same goal, work with : productivity, low costs and high performance. In this scenario the Slagless technology (which is applied into BOF converter) was important to reach this targets. After use has been reduced the number of times of nozzle exchange in more than 04 times. Was reduced too, the time to remove lance skulls. Lance keeps clean during all his life with record number of the life 1255 . Blow keep stable due strong measure control at the nozzles and more improvements are planing.

Sintering & Pelletizing / 295

Modelling and simulation of ignition hoods for iron ore sintering

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Ignition of sinter raw mix has a major influence on the efficiency and productivity of the sintering process. Basically, the operation of an ignition hood consists in setting hood temperature and controlling lambda ratio so as to adjust oxygen content in exhaust gas and ensure an efficient ignition of the solid fuel contained in the raw mix. Operators are facing the problems of generation of sinter fines due to a non-even temperature and oxygen profiles along hood width as well as reduction of permeability due to slagging phenomena. These potential problems can be limited during design of ignition hood, arrangement of burners and their technology. Additionally, avoidance of dust projections is an important point to be taken into account at the hood design stage, in order to limit maintenance works during plant shut-downs and extend burners and refractory lining lifetimes.

Thus a study has been carried out by PW in order to characterize the effect of both horizontal and vertical burners' arrangements on sintering process. During this study, pilot tests of an industrial burner have been performed at different operating parameters such as air-gas ratios,

gas composition and power ratios for establishing and calibrating a CFD model of the burner. This model has then been integrated into a CFD calculation simulating the entire ignition hood with the target to compare both horizontal and vertical burner arrangements.

This paper will describe overall results of burner tests at pilot facility and highlight differences between both burners arrangements by analysing CFD calculations.

Key words: Sintering, ignition hood, burners, low calorific value

Slags / 296

Factors of influence during and after the electric steel making process: Characterization and optimization of electric arc furnace slag

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More than 40 Million tons of steel were produced in Germany in 2015. Therefore the total amount of iron and steel slags is about 13 Million tons every year. The black slag from electric steel making (EAF-slag: approx. 2 Million tons every year in Germany) produced during the scrap melting process in the electric arc furnace can be used in the construction of roads and in other high-grade applications. There is a decades-long tradition of utilization of steel slags in general and of EAF-slag in particular in Germany, in Europe and worldwide.

The characterization of the properties of EAF-slag depends on different manufacture steps during and after the steel making process. The first step is the selection of different scrap qualities and furnace conditions for scrap melting. Furthermore the addition of slag forming materials is very important for a stable process, but also for the quality of the slag. The quality of EAF-slag is characterized as a metallurgical tool (foamy slag to protect and stabilize the process) and on the other hand as a by-product for high-grade applications (utilization instead of landfilling). Additional treatment of the liquid EAF-slag during the process or during tapping can be advantageous. After the EAF-process the cooling conditions during solidification and follow handling of solidifying slag influence the technical and environmental properties of the EAF-slag, too. The last step is the processing of the EAF-slag, final adjustment of the quality of the EAF-slag can be carried out by metal separation, crushing, sieving, recomposing and treatment of the solidified slag.

All these different steps of PRODUCTION of EAF-slag are investigated during a research project by an electric steel work (LSW), a slag processor (MAU) and a research institute (FEhS). The acronym of this research project is PROEOS (PROduction of a high quality Electric arc furnace Slag). After a status-quo investigation of more than 200 different slag samples, first operational tests have been carried out, the results will be described.

Sintering & Pelletizing / 297

Optimal mixing and granulation process for fine utilization in sinterplants

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The rapid growing iron and steel productions in the recent years resulted in a continuously demand for new iron ore resources. On the other hand the availability of the typical sinter feed (1-6.3 mm) has become limited and the rapid growing production resulted in more and more fine ore (< 150 µm) availability in the market. The sinter plant operators are facing several new challenges since the mixing and granulation- and the sintering behavior of the fines containing mixtures often differs from the traditional sinter feed's behavior. The utilization of fines in the sinter plants might increase the process water consumption required for the mixing and granulation process or even the solid fuel consumption, which effects the operational cost of the plant significantly. The current study presents an overview about Outotec's laboratory facilities and competence regarding the mixing and granulation of fines in different equipments. The usage of high intensity mixers (HIM) –vertical and horizontal as well –proved to be the most effective in case of fine ore handling. Permeability and particle size distribution curves are used to evaluate and demonstrate the efficiency of the different equipment's. Outotec's long-time experience with the different type of mixer and the modern laboratory facilities provide an excellent opportunities to optimize the mixing and granulation procedure and utilize up to 100 % fines in the sinter with a minimum decrease of plant productivity.

Sintering & Pelletizing / 298

Outotec Solution for Pelletizing Plant Low Nox emission

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Pellet production is an intensive energy process. Although, pelletizing it is a highly energy optimized process, producers are facing restriction due to restrictive environmental standards in the whole world. In order to deliver solution to this relevant topic, Outotec is developing in small scale the low NOx burner since 2012, and the expressive results are reached. In 2014 using CFD simulation, the small scale results were reproduced with very good adherence and the results of industrial scale simulation shoed the same behavior as well, it showing promising too. The present work shows the development steps, the promising results and the next step of this development is to make an industrial test of the burner developed.

Electric Arc Furnace / 300

Operation of a DC EAF based meltshop connected to a weak electrical network: A feasibility study

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Abstract A steel making factory with a DC EAF and LF requires a reliable and stable supply system to allow the correct and efficient operation of the overall plant. Not always these conditions can be fully guaranteed giving rise to the need of more flexible operating modes for the steel making factory, foreseeing the operation in different configurations: synchronous mode with the main public network, synchronous mode with the main public network plus local generation, islanding mode only with local generation. The paper describes the analysis performed to verify feasibility of the operation, which provisions are required to be adopted and the main consequences on the rating characteristics of the equipment.

Keywords Steel making factory, islanding operation, STATCOM, DC Electric Arc Furnace, Ladle Furnace, gas turbines, technical specification, power system studies, dirty and clean bus-bar.

Cokemaking / 302**Detection of coal weathering****Author(s):** Ms. ROZHKOVA, Tatiana¹**Co-author(s):** Mr. ISLER, Daniel¹ ; Ms. PARIS, Stephanie¹ ; Mrs. NARBO, Jessy¹¹ CPM**Corresponding Author(s):** tatiana.rozhkova@cpmarienau.com

Coal weathering is regularly surveyed by cokemakers in order to avoid coke quality deterioration as a result of coal rheological properties decrease. Usual Gieseler fluidity and dilatation rheological tests are sensitive to weathering, but require values of initial and oxidized coal, which makes these tests difficult to be used. For this reason, three promising weathering detection tests were selected and studied. ASTM D 5263-01 Alkali extraction test is normally used to detect coal weathering before its extraction and is recognised by coal suppliers. It was shown the ASTM test detects oxidation after coal extraction at approximately 80% of rheological properties loss (without taking into account oxidation before coal delivery). Besides, the test is not sensitive to thermally weathered coals, and coals that contain clays. In abrasion drum test coal weathering is detected as evolution of dilatation within coal grains, i.e. progression of weathering front. This test is sensitive to oxidation but is rather time-consuming. Petrographic stain test developed by Gray et al. (1976) was proved to be sensitive to weathering before and after extraction. The advantages of this test are that it can be an addition to the standard petrographic analysis used at coke plants.

Sintering & Pelletizing / 303**OUTOTEC performance services for iron ore agglomeration plants****Author(s):** Mr. ATHAYDE, Maycon¹**Co-author(s):** BERGERMANN, Matthias² ; GOUD SALAGUNDI, Basavan² ; MEIER-HEDE, Andreas²¹ Outotec GmbH² Outotec**Corresponding Author(s):** maycon.athayde@outotec.com

The sharp decline in iron and steel prices has led producers to focus more and more on existing plants and costs of production in recent years. Focus has been on optimizing plant performance to increase productivity in existing plants and decrease energy and maintenance costs (Total variable cost). In addition changing of input materials to the worse and stricter environmental legislation required adaption of plant equipments and plant operation. Outotec supports its customers with a unique range of products and services to achieve these challenging targets. For pelletizing plants, we at Outotec have focused on new developments to increase plant productivity and efficiency in three dimensions. Firstly by reducing downtimes of the plant through our maintenance services and proprietary spare parts. Secondly by improving productivity of the plant and quality of the products by special technical services and upgrade products. Thirdly by improving the controllability by digital services and special measurements. For sintering plants focus is in addition to decreased downtimes through maintenance services on the improvement of environmental and energetic performance as well as on the increase of capacity through upgrades and modernisations in the area of mixing, induration, grate and cooling. Outotec's products are supported by strong technical support for the customer by our experts on site and through test work in our own research centers.

Cost & Process Control / 305**An agent based approach for steel industries for exploitation of opportunities and challenges provided by energy markets**Mr. PIEDIMONTE, Luca¹ ; Ms. CATENI, Silvia² ; Dr. EBEL, Alexander³ ; Mr. BENINI, Michele⁴ ; Ms. MARCHIORI, Francesca¹ ; Dr. COLLA, Valentina⁵ ; Dr. NEUER, Marcus J.³

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Steel industry is an energy-intensive sector, in particular for the electrical energy consumption. The utilized energy composes a significant part of production costs and has a significant impact on the electricity network. The increasing utilization of variable renewable energy sources, such as solar or wind, lead to key role for the energy-intensive industries demand side flexibility. Thus, there is a growing need of closer cooperation between grid operators and steel industry by improving the power consumption prediction & management.

In order to optimally exploit the benefits and challenges of dynamic energy markets a flexible management of the steel production processes is required. Reliable prediction of the plant energy demand, according to the work load, is required as a fundamental basis to be able to react dynamically on market conditions taking advantage from the energy price fluctuations.

The production systems must react to the current situation by enabling or disabling process uncritical systems allowing increasing or decreasing the energy consumption on demand. In this case the production systems must adapt their strategy according to the situation focusing on minimization of global costs while considering the process stability.

A flexible solution is then required in order to achieve the multi-objective optimisation. A concept based on the multi agent systems in combination with auctions is proposed allowing calculating an optimal combination of enabled or disabled peripheral systems and or processes according to the electrical load demand, energy costs, production needs and network requests. The different plants and machines are represented here by autonomous software agents which know their current relevance for the production process and their energy consumption function. Based on these two information's each agent calculates its own impact on the global system. This impact is submitted as a bid to the auction system which then decides which agents are chosen in order to realise the foreseen actions.

Slags / 306

Influence of basicity on chromium leaching of low alloy EAF slag

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By mass, slag is the largest residue in iron and steelmaking. Due to excellent properties as a construction material slag is rising in popularity as a resource. Before slag can be used there are some restrictions that must be fulfilled of which the leaching of chromium is one. For slag to be considered inert material the leaching limit for chromium is at 0.5 mg/kg. The leaching of slag is governed by the leachability of the minerals. Not all minerals can contain chromium, by eliminating the soluble minerals that contain chromium the chromium leaching should decrease. The composition of low alloy EAF slag was altered by remelting the slag with different amounts of SiO₂ additions. By changing the basicity the mineralogical composition is altered. The compositions of the samples were identified using SEM EDS and XRD. As ageing may affect the leaching of slag, the samples were run in an autoclave to simulate ageing before the leaching test. The autoclave treatment was successful as the remelted slag without any modification leached with the same magnitude as the naturally aged reference sample.

The investigated slag had the highest leaching of chromium, at average 2 mg/kg, when basicity was 2.7. The chromium leaching decreased to 0.1 mg/kg as basicity were changed to 2.4. The decrease of leaching can be connected to the decrease of the chromium bearing phase: brownmillerite. Lower basicity did not eliminate leaching of chromium as merwinite, another mineral able to contain chromium, was formed instead of brownmillerite.

Electric Arc Furnace / 307**Soft sensors for improved control of electric arc furnaces****Author(s):** Mr. SANDBERG, Erik¹**Co-author(s):** Dr. BJÖRKVALL, Johan¹; Mr. CHRISTOFFER SCHMIDT, Christoffer²¹ Swerea MEFOS AB² KTH**Corresponding Author(s):** johan.bjorkvall@swerea.se

Today the possibility to run EAFs at optimal energy efficiency is limited due to lack of information on the scrap melting progress and steel temperature inside the furnace. This paper describes results from a research project with the aim to improve the estimation of these essential parameters through taking advantage of new experimental measurement techniques (sound, vibrations, harmonic distortions and fiber optics). Soft sensors that estimate the sought process parameters meltdown degree and steel temperature was developed utilizing a combination of the new experimental measurement devices with conventional process data (such as cooling water flows and temperatures, electrical parameters and flows of oxygen and carbon). The soft sensors have been calibrated based on real production data and measurements from a Swedish steel plant. The soft sensors have also been installed in the level-2 system at the same steel plant. This implementation will, in turn, give opportunities for improved process control so that the desired steel temperature can be achieved to as low energy cost as possible.

Industry 4.0 / 308**Danieli intelligent system: a leap forward towards the intelligent plant****Author(s):** Mr. OMETTO, Marco¹**Co-author(s):** Mr. COMELLI, Antonio¹; Mr. MERLUZZI, Andrea¹; Mr. FINSET, Martin¹; Mr. POLO, Andrea¹¹ Danieli Automation SpA**Corresponding Author(s):** a.polo@dca.it

Modern information and communication technologies like Business Intelligence, Big Data or Cloud Computing will help predict the possibility to increase productivity, quality and flexibility within the manufacturing industry and thus to understand advantages within the competition. From the first introduction of Q3Intelligence more than 10 years ago, Danieli Automation has always focused on anticipating the current trends of automation and data exchange in manufacturing technologies in order to offer the most advanced technologies to its customers, who challenge Danieli Automation in providing the most advanced system to enhance the productivity, maximizing at the same time quality without compromising the flexibility required by the modern market conditions and optimize the energy consumption. This article will lead through the technical solution of the “Danieli Intelligent System”, which consists in the seamless integration of basic modules: Q3Intelligence, Qs-Energy, Qs-Process and Qs-Maintenance.

Blast Furnace Ironmaking / 309**Hot blast stoves – Latest developments, assessment and life-time extension****Author(s):** Mr. SCHAUB, Eric¹**Co-author(s):** Mr. ALLMANNSDÖRFER, Ralf¹; Mr. CASTAGNOLA, Cristiano¹¹ Paul Wurth**Corresponding Author(s):** steffen.koehler@paulwurth.com

Hot Blast Stove Systems are an important equipment of a Blast Furnace plant. During the last years, performance requirements and operation practice for the Hot Blast Systems have changed, with a big influence on the BF operation. Therefore it is necessary to keep the Hot Blast System,

including the Hot Blast Stoves, in proper condition in order to maintain the production capacity of the Blast Furnace. For operators, it is particularly important to know about the current condition of a Stove Plant and the relevant constraints. Assessing the condition of a Hot Blast Stove Plant on a regular basis, especially in advance of a Blast Furnace reline, is therefore highly advisable.

Considering the individual condition of the Stove Plant, improvements in operation, but also specific and dedicated repairs might be implemented. Design improvements can be implemented as a part of such a repair as well.

In addition, new developments became popular during the last decade, like the so called Dome Combustion Stoves, which have been invented already 30 years ago in Western Europe.

This paper will describe some of these design improvements and will illustrate their implementation in new hot blast stoves. It will also highlight repair methods for existing stoves.

Keywords: Hot Blast Systems and Stoves; Refractory Lining; Stoves Assessment & Repair

Cold Rolling Mill / 310

An active actuator to eliminate chatter marks caused by self-excited vibrations in rolling mills without speed losses

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In hot and cold rolling mills self-excited vibrations are a very common problem. These vibrations lead to chatter marks on rolls and strip, if no countermeasures are applied. Usually rolling speed is reduced significantly in an automated way, each time self-excited vibration comes up. A reduced productivity is always the result. A new actuator is presented in this paper that allows the active damping of vibrations. This can be done at full production speed. Therefore the flat bearings of mill housing are replaced by new adaptronic flat bearings which can adapt their thickness. In case of self-excited vibrations the roll chocks are pressed automatically to the mill housing in a coordinated way, which increase the damping and thus self-excited vibrations are eliminated. This approach is useful especially for existing mills. This paper presents results of a prototype in a special vibration testbed. The general function of the adaptronic flat bearing and its capability to damp self-excited vibrations are shown.

Hot Strip Mill / 312

Robust control of the lubrication in a hot rolling process

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Lubrication is a key parameter for improving the finishing mill process in hot rolling. The lubrication changes the contact interface between the work rolls and the hot strip. The lubrication can reduce the rolling force, the rolling torque, the energy consumption, the work rolls consumption and the work rolls degradation. Lubrication is also a lever to optimize finishing mill capability. The best way to observe lubrication effect is to analyze the friction variations. Indeed the lubrication reduces the friction coefficient. In this paper, a robust control of lubrication to reduce

the roll gap friction in a hot rolling process is proposed. The model obtained from Arcelormittal experimental data is rewritten as a Linear Parameter Varying (LPV) system with delay and saturations. The formulation of the systems contains extended states in order to integrate the delay with a Smith predictor. This delay is compensated by the Smith predictor in an internal loop. The global formulation with the delay and saturations is studied to ensure the process stability against model gain error.

Industry 4.0 / 314

Data mining continuous sensor data for training plant wide defect models

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Data mining process has proved to be very valuable for addressing industrial issues such as understanding defect crisis. However, for the methodology to be successful, several key criteria have to be fulfilled:

- Data has to be relevant and well prepared
- Rigorist mathematical, statistical and modeling methodologies have to be used to assess result robustness.
- As many process knowledge as possible has to be integrated in the analysis and in the result interpretation for more relevancy

In classical data-mining procedure, only "single value" variables are considered, meaning that one individual, typically one coil for the steel industry, is characterized by average value of many process parameters (composition, temperature, speed, strengths, tractions, composition ...), which will be used to predict, forecast, estimate unknown properties about the product, such as the probability of defect occurrence for instance. However, in many situations, the available information is much wider since many sensor continuously register information about the product and the process. Theoretical tools to conduct data-mining studies with such high dimensional "time-series" data are progressively developing, following the "big data" trend of the last years. However, many open questions remains for a concrete industrial application like defining accurate statistical defect models for the steel industry.

In the PRESED RFCS (PRedictive Sensor Data-mining), the overall methodology to build a statistical defect model from time-series data bases is investigated, including the development of new theoretical methods based on "shapelet" theory, but also the use of specific ontology tools to integrate process knowledge in the model and IT infrastructure (data-base, analytics server) to get practical and usable results from realistic industrial data sets.

The paper will focus on presenting this overall methodology as well as practical example of use like sliver defect modeling or mechanical properties scattering.

Blast Furnace Ironmaking / 315

Unconventional reducing agents for sustainable blast furnace ironmaking

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Reducing agents are considered to be the major portion of hot metal production cost in blast furnace (BF) ironmaking. In addition, lower energy consumption, lower CO₂ emission and waste recycling are strongly needed from both economic and environmental perspectives. Therefore, the iron and steel industry is prompted to sustainable develop “coke free, zero waste and green processes” for future implementation. In the present overview, attempts to explore the possible usage of unconventional reducing agents in BF ironmaking will be discussed. The paper aims to explore the feasible utilization of different carbon bearing materials as reductants in the BF ironmaking process. Different carbon bearing materials is considered, namely, waste plastic materials, biomass, and carbon rich iron and steel industry wastes. Devolatilization and gasification of carbon containing plastic and biomass materials are investigated by means of thermogravimetric analyzer coupled with an evolved gas analyzer. On the other hand, pretreatment of integrated steel in-plant fines prior to its utilization as a source of not only carbon but also iron is explored followed by a study of its reduction characteristics.

Byproducts / 318

Combined PtL and Use of by-product H₂ in an integrated steel mill - Industrial symbiosis between chemical and steel industry

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The generation of renewable electrical energy will not fulfil the electrical energy consumption at any time. Therefore there will be “surplus” electrical energy in the electrical energy system that must be used to gain grid stability. The PtL technology consumes that “surplus” electrical energy and incorporates simultaneously the substantial usage of CO₂ as feedstock for its conversion to methanol or liquid fuels via MTG or FT process. CO₂ based methanol production in accordance with the PtL concept is realized in Iceland by Carbon Recycling International. Feedstock is CO₂ from the geothermal steam of a nearby power station and H₂ from water electrolysis by means of renewable electrical energy. Integrated steel mills are industrial parks with coke-, iron and steel making. Their process gases are coke oven gas (COG), blast furnace gas (BFG), and converter gas (BOFG). COG contains more than 60 % H₂ and BFG more than 20% CO₂. They are used within the steel production chain for heating purposes as well as for power generation to become energetically selfsufficient. Extracting CO₂ out of BFG and converting it to methanol lead to CO₂ emission avoidance in the gas combustion processes within the steel mill. It will be shown that the profitability of the PTL application will be enhanced in terms by combining it with the use of industrial by-product hydrogen to an extended PtL application. That will be demonstrated exemplary by its use within the environment of an integrated steel mill showing symbiosis between chemistry and steel industry. Beneficial for that are 1. The availability of substantial amounts of unused low temperature heat sources for covering the energy demand of the CO₂ supply and methanol distillation, 2. the demand of substantial amounts of oxygen for the blast furnace as well as the converter process, and 3. the use of process heat via the steel mills steam grid.

Rolling / 319

Investigation of through-thickness texture of a 1.24% Si electrical steel

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An electrical steel with 1.24wt.% Si was hot rolled, hot band annealed and cold rolled (CR) to a rolling reduction of 78%. The as-CR specimen was subsequently annealed at the temperature range between 500°C and 900°C, and Vickers microhardness tests was performed on these specimens to determine the recrystallization (RX) temperature. Recrystallization was found to start at the temperature of 620°C and finish at the temperature of 700°C. Pole figures of these specimens were obtained by using X-ray diffraction and microstructure characterizations were carried out by the use of electron backscatter diffraction (EBSD) technique. The through-thickness textures of the CR and annealed specimens were analyzed at five depths. It is found that Goss orientation, {110}<001>, appears to be significant at the sub-surface layer at the early stage of RX. Examinations of the microstructures reveal the presence of many shear bands. The direct observations of the same areas after annealing indicate that many of these shear bands are the potential nucleation sites for RX.

Refractories Steelmaking / 320

Torpedo ladle: Monolithic lining improvements

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For the process of obtaining steel, pig iron produced in the blast furnace must be treated by a series of transformations called refining. Torpedo ladles carry melted pig iron at temperatures around 1500-1650°C from the blast furnace to the steel mill through a railroad. Generally, the refractory lining of the torpedo has three layers with silicon carbide bricks in the working lining which is in contact with melt pig iron and therefore suffers high wear. As coating thickness decreases, partial repairs are made with refractory concrete to increase the torpedo lifetime. In this sense, PASEK is a manufacturer and supplier of these products, and also has the required equipment and staff to do the maintenance of torpedo ladles. Working in continuous improvement, in the last time, PASEK has been development a range of silicon carbide shotcrete refractory concretes for torpedo repairs, which increase the lining performance and thus decreasing the number of needed repairs, optimizing operation costs. Silicon carbide hardness gives high abrasion and shock resistance to the concrete, resulting in excellent thermo-mechanical properties at high temperature. Finally, in order to reduce energy costs and optimize safety during concrete drying, PASEK goes one step further with the installation by shotcrete of non cement, silicon carbide based concrete. This technology known as PASEK FASTDRY (FD) decreases the drying time in more than 60%, significantly reducing energy costs associated, thereby improving material hot properties and increasing the lining efficiency. Analysing the life of torpedo ladle lining, the number of repairs and quantity of refractory use to make the repairs, it is possible to obtain a comparative between the cost of refractory lining with dry or wet gunning.

Electric Arc Furnace / 321

Dunite patch for slagdoor and hearth lining EAF

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The slagdoor is the part of the electric furnace for the slag bleeding occurs. This door is closed by a metal door that rises at the time of casting slag, dropping back to its initial position to continue the process of steelmaking. During the casting, the erosion or attrition of the refractories lining that cover the sidewalls of the furnace takes places, so it is necessary to apply a material which allows that useful life of those refractories is extended at the same time that protect the electrodes and facilitate the clean of the slag residues. The protection of the slagdoor comprises several parts: protecting the refractory lining, the electrode and facilities cleaning of slag. PASEK Dunite is an ultramaphic rock exploited in the north of Spain with a basic chemical classification, being olivine and serpentine its principal minerals. As a result of its composition, its physical and mechanical properties and availability of different grain sizes according to customer requirements, PASEK Dunite is a suitable material to protect the slagdoor during the casting. The main products for this applications are magnesium derivatives as magnesite and dolomite, besides the use of Dunite has several advantages such improving the clean os slagdoor, lower cost of acquisition and No CO2 emissions. On the other hand, the same product could be used as ramming mix in combination with magnesite mixes, to protect the refractory lining of EAF hearth line. In this case, is possible to have a tailor made heart lining changing thickness, thermal conductivity and compression strength of final lining.

Keywords: Slagdoor; Heart lining, EAF; Dunite; magnesium silicate, runner patch

Oxygen Steelmaking / 322

Value in use of pasek dunite in the BOF process

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The aim of the BOF (Basic Oxygen Furnace) process is to convert carbon-rich liquid hot metal from the blast furnace to low-carbon steel, which may be refined in the secondary steelmaking shop. Fluxes are needed in this process to remove impurities from the liquid hot metal and form an appropriate slag which could be easily separated from the steel. These fluxes could require low melting points to reduce the energy consumption, to fluidize the slag at lower temperatures and remove impurities from steel. It is necessary for the fluxes to have an appropriate granulometric distribution, good tumbler index to reduce fines generation which could obstruct the blowing plugs, so a homogenous flux is desired. A homogeneous chemical composition that allows basicity control (Si and MgO levels) and high absorption characteristics to combine the flux with P, S, Si, etc. are needed. PASEK Dunite is an ultramaphic rock exploited in the north of Spain with a basic chemical classification, being olivine and serpentine its principal minerals. It is formed by orthopyroxene, clinopyroxene and olivine in variable proportions. An important parameter in this kind of process is the ratio pig iron/scrap (Hot Metal Ratio, HMR). This parameter shows the thermal balance of the process and measures the consumption of pig iron per tonne of liquid steel. With high hot metal ratio, more phosphorus amount is necessary to remove in comparison with a low hot metal ratio, so it is necessary to increase the slag amount maintaining the basicity and the MgO level. In this case is recommended to use Dunite for increase the slag quantity and the dephosphorization percentages. PASEK Dunite is a good flux for BOF process and its use is recommended when the BOF produces low silicon content slag and high levels of slag are needed, maintaining its basicity and MgO content, as well as if the process works with a high hot metal ratio (high phosphorus amount to remove).

Keywords: Fluxes; Dunite; Hot Metal Ratio; BOF; Magnesium Silicate

Sintering & Pelletizing / 323

Value in use of Pasek dunite improving the return sinter fines

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The purpose of Sinter plants is to heat iron ore fines along with fluxes and coke fines or coal, to produce a semi-molten mass that solidifies into porous pieces of sinter with the necessary size and strength characteristics for feeding into the blast furnace. Fluxes used in the sintering process need to have an appropriate granulometric distribution and TI (tumbler index) to avoid generation of fines, which could obstruct the blowing plugs and reduce the productivity of the Sinter. Besides, a homogeneous chemical composition and high absorption characteristics are necessary to control the basicity (Si and MgO levels) and to combine the flux with P, S, Si, etc, respectively. PASEK Dunite is an ultramafic rock exploited in the north of Spain with a basic chemical classification, being olivine and serpentine its principal minerals. PASEK Dunite is a very homogeneous and hard stone and its main characteristics are: high hot and cold resistance to mechanical stresses (shatter / crushing / abrasion), softening and melting points of a flux not of a refractory material, which provides a compact and high quality index sinter, with good strength and homogenous MgO distribution. In addition, due to its mechanical and chemical properties, less fines are generated in the sintering process and during the handling and transportation to the blast furnace, improving the productivity of these processes. In this way, the use of PASEK Dunite allows increasing the homogeneity structure of sinter, reducing the percentage of return fines and improving the Sinter productivity.

Keywords: Fluxes; Dunite; Sinter; return fines; Magnesium Silicate.

Rolling / 324

Advanced HSS grades – Key material for rolling of steel with high efficiency

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The increased demand for higher precision and lower tolerances of rolled steel products poses an enormous challenge for the development of roll materials.

New high speed steel grades **HSS** offer a solution in many cases for hot strip mills, strip casters or plate mills because of their extreme wear and heat resistance as well as superior surface properties. For **early roughing stands**, a new **semi-HSS** quality **SST-mod** is introduced providing extraordinary thermal stability in combination with reduced wear and optimum friction. Performance data will be presented.

A new full **HSS** quality **SST** has proven its efficiency in late **roughing, reversing roughing and early finishing stands**. With such new **SST** grades, surface quality and crown of the roll can be retained much longer, even in plate mills. The surface quality of the rolled product is considerably improved.

The extreme wear resistance of new graphitised **HSS** grades also opens up opportunities for late finishing stands: **Graphitised HSS** materials called **SST-G** are increasingly used and provide significant improvement compared to conventional roll materials e.g. enhanced indefinite chill double poured ICDP. Dimensional accuracy and surface properties of the rolled products are much better and allow an increase in campaign length by a factor of two.

Thus, the total cost of ownership TCO for the whole mill will be reduced.

Rolling / 325**Opportunities of experimental and numerical simulation of steel rolling technologies at the Institute of Metal Forming of TU Bergakademie Freiberg****Author(s):** Mr. SCHMIDTCHEN, Matthias¹**Co-author(s):** Mrs. STÖCKER, Anett² ; Mr. ADAMYANETS, Pavel² ; Prof. KAWALLA, Rudolf²¹ *TU Bergakademie Freiberg, Institut for Metal Forming*² *TU Bergakademie Freiberg, Institute for Metal Forming***Corresponding Author(s):** matthias.schmidtchen@imf.tu-freiberg.de

Actual improvements in rolling e.g. in relation to power requirements, energy consumption and final material properties demand powerful and robust simulation tools for process optimization, pre-setting calculations or automation. The semi-industrial rolling equipment of the institute of Metal Forming of TU Bergakademie Freiberg is used during the period of simulation development as well as for evaluation purposes to ensure robust tool developments and practicable material technologies for flat and rod rolling. To illustrate the efficiency of these opportunities examples from flat and rod rolling as well as cladding are given. Focus of all actual developments are laid on a fast simulation of the heterogeneity of deformation. Therefore results in experimental and numerical simulation of direct charging, for Fe-Si alloys rod rolling of several steel grades or cladding are discussed. This presentation gives a short review of this model approaches and highlights some important stages of development.

Secondary Metallurgy / 326**Assessing the effect of two different deoxidation practices on non-metallic inclusions and mechanical properties and their evolution with thermomechanical processing.****Mr. NARANJO-ESPINOSA, Jose Manuel¹**¹ *Sheffield University***Corresponding Author(s):** jmnaranjoespinosa1@sheffield.ac.uk

For the present investigation, the same steel grade has been produced with two different deoxidation practices namely Al and Al-Si killing. There has been reported that deoxidation with Si reduces costs and decreases castability issues associated with Al. Material from both practices has been characterised in the "as cast" and "forged and rolled" conditions. The differences in terms of inclusion content and subsequent processing have been evaluated using different techniques (Optical Microscopy, Scanning Electron Microscopy and Automated Inclusion Analysis) and industrial standards (ASTM E45 and Ultrasonic MIDAS Testing) and the results will be reported.

Rolling / 327**Challenges in the steel industry and consequences for rolling plant technologies****Author(s):** Mr. BUCHMAYR, Bruno¹**Co-author(s):** Mr. DEGNER, Michael² ; Mr. PALKOWSKI, Heinz³¹ *Montanuniversität Leoben*² *SMS group*³ *IMET***Corresponding Author(s):** bruno.buchmayr@unileoben.ac.at

This paper provides a short overview of recent steel market developments considering the global steel oversupply and recessions in some emerging economies. The enormous Chinese overcapacity combined with their lower demand is a major reason for the deterioration on the steel market.

The general steel demand also declines due to slow growth or even reductions in technology fields like ship building, thermal power plants, infrastructural needs or even the automotive industry. Nevertheless, environmental and energy-efficient production routes are of primary interest, which are partly handled by thin strip production. TMCP remains a main research field for many applications. Increased demands are expected regarding enhanced strength for light-weight design, improved toughness to ensure safety in case of earthquakes and fires or improved formability to overcome geometrical limits. New steel grades like bainitic steels, nano-crystalline materials, TWIP-steel or grain-oriented electrical sheet metals have led to advanced quality criteria also for rolling plants. Some recent examples of innovative processing optimizations will be described which require not only process monitoring but also model-based simulation and real-time online control. Finally, it will be stated that new holistic strategies are necessary to overcome the future challenges.

Long Products / 328

The journey of one square millimeter wire surface

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Wire surfaces undergo many transformations on their way to the finished product. They are a very important key factor for the strength and quality of the wire. Fine steel wires have a small diameter such as 80 to 150 µm, however they have to resist high strength up to 3900 MPa during their application. During their production, any kind of surface damage has to be avoided. Another important issue, which has to be handled carefully during production of fine wires, is the scale. The aim of this work is to collect and describe the surface defects characteristics of rolled and drawn fine steel wire. The severity of the characterized flaws is described and rated. The development of the surface defects was observed over the producing process and the effects on the final product are visualised. Methods of finding suitable scale compositions for the fine wire production are declared and the characteristics of the scale are defined. To reenact the mechanical descaling on a lab scale, the wire samples were bended step by step by using a bending machine.

Secondary Metallurgy / 329

Identification of peritectic grades of steel using high temperature phase transformation studies

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The thin solidifying shell in the meniscus region of continuous caster deforms due to severe contraction of steel during solidification for near peritectic composition of steel and there is potential risk of cracking and in the extreme cases, breakout of shell. The main purpose of the present study was to contribute an improved understanding of peritectic transformation through high temperature experimentation. Peritectic grades of steel are cast at slower speed due to these phenomena. So to increase the productivity of a caster, peritectic grades of steel should be accurately identified so that other grades can be cast at higher speed. There are several methods which are being used to identify peritectic grades. Most shop uses ferrite potential formulae to identify if a particular steel grade will behave as peritectic or not. In the present study a high temperature experimental technique was used to identify peritectic grades of steel. Differential scanning calorimetry (DSC) is a technique which was used to identify any type of reaction or

phase transformation which is associated with enthalpy change. Using this novel technique, more than 80 steel samples of different chemistry were studied to identify peritectic grades. Peritectic grades will have an enthalpy change for both peritectic transformation and melting, whereas for low carbon only melting takes place. So a single peak close to melting temperature of steel is considered a low carbon grade whereas two peaks near melting temperature is considered as peritectic grade. The DSC measurement was further substantiated through calculated thermal variation coefficients (TVC) and the outcome of a new ferrite potential formula. It was observed that out of all steel chemistries 50% of steel chemistries which were being cast as peritectic were identified as low carbon and can be cast at higher speed.

Rolling / 331

Developing heat treat equipment for 3rd generation AHSS

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The many new steels being developed to address the light-weighting car initiative put new demands on the thermal processing equipment in order to obtain the desired mechanical properties. Higher annealing temperatures, faster cooling rates, tighter control of the cooling curve, better strip shape and more uniform tempering are needed. Interestingly, many of these demanding requirements are already addressed on smaller scale continuous harden and temper lines.

Now concepts have been developed to increase the width of the strip to 300% over the average harden and temper line and to increase the throughput to 2000% and more over the same. This results in production capability suitable for many applications required by the automotive manufactures and their tier 1 suppliers.

Industry 4.0 / 333

Industry 4.0 in rolling mills enabled by proactive quality assurance

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Smart factory, high flexibility, short time to market & efficiency in industrial scale are key words of Industry 4.0. The growing quality requirements in high end products are same time an enormous challenge, which are very often in competition with efficiency targets and market driven cost cutting measures.

This paper describes the implementation experience of ExpertShell system and the achieved benefits of an innovative new Industry 4.0 technology. It opens the chance for a new way of using all the available experience inside a mill to improve the work flow and increase efficiency in a new dimension. This technology helps in principle all production lines in all grades but has the highest impact in challenging grades like ultra-high strength specialty steel, electric steel and especially automotive applications.

The new solution has an embedded automatic improvement cycle, which is making sure that needed modifications and adaptations to new market requirements are taken care instantly. Speed of adaptation and reliability in delivered quality will be the differentiator of the upcoming years. Interestingly the investment in proactive quality assurance not only improves competitive position in quality, but has proven return of invests figures below one year.

Secondary Metallurgy / 334

Analysis of multi component oxides by calibration-free laser-induced breakdown spectroscopy

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Laser-induced breakdown spectroscopy (LIBS) is a promising method for fast and quantitative element analysis of complex materials. We report on LIBS measurements of multi-component oxide materials and the compositional analysis of materials by a calibration-free (CF) method. This CF-LIBS method relies on modeling of the optical emission of laser-induced plasma assuming local thermodynamic equilibrium. Various materials are investigated and the calculated concentration values (CCF) of metallurgical important oxides CaO, Al₂O₃, MgO, SiO₂, FeO, and MnO are in agreement with nominal concentration values (CN) from reference analysis. Slag samples from industrial steel production are analyzed on site by means of a mobile measurement system. LIBS measurements are performed at different sample temperatures. The results obtained show that CF-LIBS is applicable to fast compositional analysis of complex materials in harsh environments.

Rolling / 335

Improving reliability for steel mill furnace rolls

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Improving Reliability for Steel Mill Furnace Rolls

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Atlas was approached by a major steel manufacturer and asked to develop methods to improve overall reliability of steel mill furnace rolls. To accomplish this it was determined we would need to develop methods to inspect new, used and failed furnace rolls to determine why they fail and how to avoid it.

Destructive examination tests were performed on used and failed furnace rolls to determine causes of failure. Phased array ultrasonic testing and fluorescent dye penetrant testing were developed to identify these flaws through non-destructive examination (NDE) methods that could be applied to rolls that may be put back into service.

Through the destructive and non-destructive examination methods it was determined that the leading causes of premature roll failure stem from poor weld filler metal choices, poor welding craftsmanship and low quality castings.

To improve furnace roll reliability Atlas has qualified materials suppliers, developed qualified weld procedures and developed NDE methods to qualify new and used and rolls for service. It is expected that implementation of these methods will lead to improved furnace roll reliability.

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Oxygen Steelmaking / 336

Successful revamping of sublancemanipulators for the LD-converters at voestalpine Stahl GmbH – safe of process time and availability

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To further reduce process times and increase availability at the LD converters in the high-performance steel mill of voestalpine Stahl GmbH in Linz, Austria, the old hydraulic sublance manipulators were replaced with three new robotic sublance systems by Primetals Technologies Austria GmbH. The main criteria for the project were: high availability of >98 %, short cycle times in sublance-probe handling of less than 60s, fully automatic probe replacing in confined spaces, fully automatic probe supply from customized exchangeable containers, monitoring, testing and calibration of sublances, low maintenance, latest safety standards, and ergonomic design. The old manipulator was dismantled and the new robot solution installed during a 5-day converter relining. Performance was excellent already during the first days and an availability of already 95% was achieved in startup period. The system sets new standards in automation and follows the voestalpine philosophy of being one step ahead.

Keywords: BOF process, sublance, robotic, fully automatic probe manipulation, high availability, new plant system,

Byproducts / 337

Zinc oxide from steel mill dust - A wide range of opportunities

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Zinc enters the steel production through the feeding of galvanized steel scrap into the electric arc furnace (EAF). Based on the process conditions, the zinc oxide gets reduced, evaporates as metallic zinc, reoxidizes to zinc oxide in the offgas and gets collected in the filter house. Beside zinc, which represents the main component, elements like lead, iron, cadmium, sodium, potassium, fluorine and chlorine form part of the dust. In the EU, this dust is declared as hazardous waste, while 1.5-2.5 million tons of EAF dust were produced in 2015. This corresponds to a zinc amount of approximately 900,000 - 1.5 million tons. Due to the zinc content the EAF dust displays an usable by-product for the production of different products. This paper deals with the different opportunities to produce products for the zinc market, using EAF dust as raw material. A focus is set on the production of waelz oxide followed by strategies to form different zinc products such as oxides, sulphates, carbonates and also a metallic shape. Furthermore, the paper deals with the different product qualities which are generated depending on the process steps.

Oxygen Steelmaking / 338

First operating experiences with post-combustion lances at BOF shop LD3

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The application of post-combustion to avoid skull formation on BOF lances was tested in industrial trials. The main findings are that no negative impact on the metallurgical targets (i.e. carbon, temperature and phosphorus at end of blow as well as iron-oxide in the slag) could be observed.

The technology is capable of avoiding the buildup of lance skull and consequently increasing the average life of lance tips. The application of post-combustion not only affects the skull formation, there are also interactions with the refractory lining, especially thermal wear, and the utilization of the process gases that have to be considered. Special attention has to be paid to the parameters determining post-combustion because rather small changes can strongly affect the points mentioned above.

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Impact of carbon, silicon and manganese contents on the dissolution and melting behaviour of scrap in a dynamic BOF model

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Since the development of basic oxygen furnace (BOF) the modelling of the process reflects a huge field of activity due to the accelerated increase of BOF steel plants. The optimization of the BOF process is focussed, amongst others, also on the thermodynamic and kinetic modelling. With the program MatLab® a new BOF model has been developed. One of the main topics is the description of the melting and dissolution behaviour of scrap in the BOF. This paper deals with the influence of different Carbon, Silicon and Manganese contents in scrap on their effect on the dissolution behaviour during BOF process. Additionally the influence on the final temperature, metal and slag behaviour will be shown.

Environmental / 341

Challenges to the steel industry in the transformation process towards low-carbon economy at the example of voestalpine

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Climate issues are inseparably linked with energy and industrial topics. For (European) steel industry and in particular for voestalpine, this refers one the one hand to our **customers and markets** (nearly two thirds of Group revenue are generated with the segments energy and mobility), and on the other hand [U+2015]equally important [U+2015]to our **production processes and products**, which are crucially affected by the transformation process related to the global climate targets 2050.

As a matter of fact, **steel industry** is not part of the problem, but due to its huge economic importance and its sustainable products **essential for the solution**. For example, steel applications for “energy transition” saves six times the energy and thus CO₂ as consumed in their production. **Steel is key part of value chains that are fundamental for a low-carbon future.**

But most of all it has to be understood, that “**less CO₂**” **does not mean “less energy”**. Conventional steel production with blast furnace and blast oxygen furnace routes (still three quarter

of global crude steel production) is [U+2015] due to pure chemical-physical reasons [U+2015] based on coal/coke as reducing agent as well as most important energy source. **Fossil sources are the basis of integrated energy cycles and nearly self-sufficiency with energy.** At the example of voestalpine alone, replacing fossils by renewables would correspond to an *additional* demand of 33 TWh or more than 30 water power plants.

We have been consistently **working on breakthrough technologies with regard to low-carbon-steelmaking** for many years, e.g. **based on renewable hydrogen**, and are currently developing projects with the largest Austrian energy supplier.

However, there are key preconditions for transformation: It has to be **feasible and realistic, not only from the technological point of view, but also economically.** And if politics declares **climate targets**, it has to make sure, that the **required energy is available at competitive prices and in sufficient quantities.** Otherwise, transformation will simply not happen or [U+2015] even worse [U+2015] **at the price of de-industrialization of energy-intensive sectors in Europe.**

This is a price, that hopefully no one is willing to pay. **So let's focus together on solutions, not only on political declarations.**

Secondary Metallurgy / 342

Characteristics of ladle flow field by gas bubbling method

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Flow Phenomena and mixing characteristics of the molten metal bath have been investigated according to the bottom bubbling gas conditions. The mixing time of the bath was affected from the location of gas bubbling plugs on the bottom of the ladle and numbers (from 1 to 3 plugs). For the same number of bottom bubbling plugs, the bottom bubbling in the center of the ladle showed the shortest mixing time. As increasing the distance between plugs, the mixing time of bath was increased. The location of bottom bubbling plugs contributed to the flow velocity. The plugs located to the close the ladle side wall interrupted the bath flow each other therefore, it led to the increase of mixing time. As increasing the number of bottom bubbling plugs, the mixing time of bath flow was decreased. For the number and location of bottom bubbling plug in the bath, the shortest mixing time was existed. For the case of changing the bottom bubbling flow rate periodically, the mixing time of bath flow was investigated. The periodic flow rate of the bottom bubbling also changed the mixing time in the case of using same bottom plugs. The short-periodic flow rate showed the decrease of mixing time compared with the normal bottom bubbling flow rate. When period of bottom bubbling flow rate got longer, the mixing time converged on the specific value. For the condition of periodic bottom bubbling flow rate, as total bubbling flow rate was increased, the mixing time was decrease, but the decreasing rate of mixing time was increased.

Secondary Metallurgy / 343

Physical modeling of bottom gas injection in metallurgical ladles: Status and current challenges

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Electromagnetic, mechanical or gas stirring can improve thermal, mechanical and chemical mixing. Bottom gas stirring is the dominant method. Physical modeling has been extensively employed in the past 40 years to describe mixing phenomena due to bottom gas stirring in metallurgical ladles. The opacity of the steel/slag system and its scale are two factors that impose limitations

to fully describe mixing phenomena employing industrial size ladles. By using a water model the bubble plume, bubble size and recirculation loops are easily observed. Mixing efficiency is measured in terms of mixing time, however, mixing time is a parameter that depends on many process variables: gas flow rate; number, radial position and separation angle of porous plugs; slag thickness, ladle aspect ratio, diameter of porous plug, tracer concentration, position of tracer measurement probe, etc. In the first 30 years, the top slag layer was neglected. It is well known today that the top slag layer promotes drastic changes on mixing phenomena. Our current understanding from physical modeling is still far from complete not only because an accurate representation of the real steel/slag system is still missing but also due to the challenges to keep constant relevant process parameters during the experimental work. This situation explains the broad optimum conditions reported by many re-searchers in the past.

Industry 4.0 / 344

Advanced data-driven prediction models for BOF end-point detection

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With increasing computing power, data storage capacity, advanced algorithms and innovative sensor technologies it is today possible to approach the BOF process from another point of view: machine learning models and Data-driven Prediction Models (DdPM). These approaches process large amounts of data to predict the BOF process conditions, e.g. temperature, carbon and phosphorus content of the melt at the end of blowing (EOB). In a cooperative effort between SMS group and ArcelorMittal Gent, a detailed study based on approx. 10,000 BOF heats has been carried out. The target values of the investigation were chosen to be melt temperature TEOB and carbon content [%C]EOB. In an off-line analysis, different strategies for preprocessing and validation were employed in combination with several supervised learning approaches (e.g. Bayesian regression, Support Vector Machine (SVM), deep neural networks (DNN)) as well as different learning schemes (e.g. sliding learning). The data-driven methods can either directly predict the target values TEOB and [%C]EOB or predict deviations from the already existing metallurgical model to improve the prediction accuracy. The metallurgical model is based on known physical and chemical correlations, i.e. mass balance, energy balance, and statistical equations. It could be assessed that the DdPM model provides a higher prediction accuracy as compared to the conventional model. One aim of using offline DdPM approaches is to gain a better understanding of influence factors such as scrap type, lance pattern etc., to detect drifts or shifts in the process and to improve the metallurgical model. In a next step, the DdPM approach shall be incorporated in the online BOF process control in order to improve the model proposal and prediction accuracy. Due to the fact that SVM, DNN are not easy to interpret, the use of DdPM as a stand-alone unit might be an additional option. The paper summarizes fundamental R&D work of the partners, focuses on the applied mathematical models and shows DdPM potentials.

Blast Furnace Ironmaking / 346

A new practical engineering approach to improving the service sustainability of copper staves in blast furnaces

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1. Copper staves are being used widely as blast furnace body cooling components. Blast furnace production and life-time sustainability is directly related with the durability of the copper staves. Copper staves protects the refractory and furnace shell from the heat load and adverse mechanical effects due to the formation of an accretion layer. Since the stove maintenance and replacement is almost impossible due to their hard-to-reach location during the BF is in service, performance sustainability of the copper staves have crucial importance in terms of blast furnace productivity and life-time as well. High level productivity and longer blast furnace service life- time can be achieved by a trouble free copper stove cooling system. In this paper, root causes of the copper stove failures are investigated, a new approach for the risk of these failures is presented, and binary logistic regression analyses of the blast furnace design and operation parameters are performed.

Environmental / 348

Risk assessment for lubricants in use in steel plants. How fire resistant lubricants improve work safety and reduce fire hazard in steel plants

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Fire hazard in the steel industry is not a new topic and the steel industry is taking any possible efforts to lower the fire hazard in its production plants. Fire hazard is present in several different forms, but fires induced and intensified by mineral oil based lubricants are notorious and feared. For hydraulic fluids several alternatives are available, but for lubricating greases fire resistance is a greenfield area. This paper explains the Risk Assessment process a company can go through to make a proper estimation of the risk involved and how the evaluation of the several alternatives can be made. Finally the paper describes what change can be made to the choice of lubricants to get to a situation with significant reduced risk, enhanced work safety and a secured productivity in Continuous Casters, Hot- and Cold Rolling Mills.

Industry 4.0 / 349

Manufacturing execution systems MES 4.0 from SMS group

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MES systems constitute the central information and management platform for the entire process sequence of a plant and its ancillary equipment in the metal-producing industry. It is linked with the automation systems of all plants and it receives status information, production data and process data. In the SMS group X-Pact® MES 4.0 modules, comprehensive technological control systems ensure that the following is achieved: • Optimum production sequence with minimum set-up time and efficient energy consumption • Optimum targets for the production of maximum quality with efficient utilization of materials and the saving of plant resources • Intelligent strategies for alternative measures in cases of malfunctions • Comprehensive data collection and evaluation for creation of potential improvements This therefore allows the plant

owner to achieve the highest possible yield with the best possible product quality, efficient use of energy and materials and sparing consumption of plant resources. The newly developed MES module X-Pact® business intelligence extends the already excellent MES by a browser-based business platform. It serves to summate, evaluate and display the technical, economic and ecological business data of the entire stock of production facilities and, at the same time, it assists in achieving potential improvements for every kind of business challenge.

Secondary Metallurgy / 350

Secondary Metallurgy No. 4 - The answer to the future quality demands at voestalpine Stahl GmbH

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In November 2015 voestalpine Stahl Linz started up its secondary metallurgy No. 4. This facility consists out of a ladle furnace, a RH vacuum degasser and a trimming stand and is located in the east of the steel plant just opposite to the slab caster CC 7. Already in the early phase of a feasibility study it was decided that this secondary metallurgy will be an investment for the 'high end' quality segment.

Beside the secondary metallurgy itself it was also necessary to install auxiliary equipment, like a secondary dedusting unit with 700.000 m³/h, a ladle tilting/preparation stand and three ladle preheaters. Additionally numerous relocations of existing equipment were required in order to get space for these new installations.

Strategic focusing on the topmost quality segment requires a consequent fine tuning of the entire process chain. Together with the extension of the secondary steelmaking capacity of voestalpine's LD 3 steel plant in Linz continuous increasing demands on quality as well as logistics are covered. The 'metallurgical link' of a RH degasser and a ladle furnace using common ladle cars has been proven successfully, based on the experience of two similar existing configurations. Supplementary, the new concept of the secondary metallurgy no. 4 was extended by utilizing an additional trimming stand for desulphurization and wire feeding as well as a third crane lifting position.

The ladle furnace is installed with a 25 MVA transformer and thus heating rates up to 5 degrees per minute can be achieved. Moreover the ladle furnace is equipped with a lance injection system for desulphurization which can also be used for rinsing, an automatic coupling system to the ladle bottom rinsing bricks, four lines for wire feeding and in total 20 alloying bins for the numerous Fe-alloys and slag conditioning materials. The ladle furnace cover is copper plated in order to avoid skull built-up on the lid, coming from a very low ladle free board.

The RH degasser is equipped with a four stage steam ejector pump with two parallel ejectors for the high amounts at the beginning of the vacuum process. A pressure of 1 mbar can be achieved within 5 minutes. A combination of burner and oxygen lance is installed for heating and deskulling the refractory of the vessel. The oxygen lance is used for adjusting the correct carbon to oxygen ratio and can also be taken for chemical heating. The alloying system with the 20 alloying bins is used commonly with the ladle furnace. Furthermore there are two micro alloying bins for smaller, but more accurate amounts of additions and two further vacuum bins. The trimming stand is equipped with a centric positioned lance injection system for desulphurization, four lines for wire feeding and again, like on ladle furnace and RH-degasser, with an automatic coupling system – here also with the possibility of soft bubbling for inclusion separation. The treatment on the trimming stand is done under a ladle cover, similar to the ladle furnace, which is also interchangeable between those two facilities.

All three installations are equipped with an automatic sample and temperature device, including a vacuum sampler on the trimming stand which meets special demands for analyzing lowest contents of residual elements. Hydrogen measuring systems are available on the ladle furnace and the RH degasser.

The whole secondary metallurgy no. 4 is operated from one common control room. All metallurgical operations are done on the level 2 system, the process observation is followed either on the level 1 system or on over 20 different camera positions/screens. The installation was also designed in conformance with the safety regulations of the EN DIN norm 14677. Therefore, amongst many other required safety items, a key transfer system is applied. On one hand this system prevents unauthorized access to plant components and on the other hand provides safety to people working on plant components from unintentionally caused movements.

Beside the logistic advantages within the steel plant process flow, the new facility shows excellent metallurgical results. Multiple treatment steps can be operated at three optimized aggregates. For example, the treatment steps of grades for heavy plate and high strength hot strip consist of desulfurization by injection at the trimming stand, alloying and adjustment of temperature at the ladle furnace and fine tuning of the analysis and degassing at the RH degasser. Finally the inclusion modification is done again at the trimming stand.

On the other end of the production spectrum ultralow carbon grades are tapped with low tapping temperature in order to relieve the converter from excessive refractory wear. These grades are heated in the unkilld' status on the ladle furnace and are then vacuum-treated on the RH-degasser. In case of operational necessities it is also possible to run the new secondary metallurgy in asplit' mode: one steel grade with low heating requirements is prepared for the RH-degasser and finally treated there and sent* to a CC, while the other steel grade is produced as non-vacuum treated steel grade on the ladle furnace for another CC.

The full strength of all 4 secondary metallurgical installations in the steel plant LD 3 will come to its final fulfillment in terms of capacity and quality requirements after the commissioning of the new CC 8 in autumn this year. By this time the aimed direct logistic link' between one secondary metallurgy' to one CC-machine will be given.

Rolling / 352

Numerical modelling and simulation of the rolling of large diameter bars

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The article focuses on the hot rolling of large diameter bars (round bars of 500mm) using either continuous casted blooms or ingots. This kind of product is often manufactured by forging an ingot. The forging process is able to applied large deformation and thus to ensure a good metallurgical microstructure (small grain size, no porosities or micro-cracks...). However, this process has two main drawbacks: it has a lack of productivity and the dimensional quality of the forged bars is poor. In comparison hot rolling allows avoiding these drawbacks but the strain applied at each pass is limited by the fact that the bar should enter between the cylinders of the rolling mill without slipping. The hot rolling route has to be determined to avoid the slipping of the bar in the mill and to generate the necessary deformation to refine the material structure.

The presented work is dedicated to the numerical modelling and simulation of the rolling of large diameter bars on the Acciaierie Bertoli Safau S.p.A. (ABS) industrial facility called ROTOFORGIA. The objectives of the simulation are twice:

- to validate the rolling route according to the bar non-slipping and the geometrical quality conditions
- to allow following the microstructure parameters associated with the porosity, the internal cracks, the initial microstructure obtained by the simulation of the continuous casting of the bloom or of ingot casting.

In a first step, the rolling process is modelled and simulated with Forge.NxT software. The rolling route is made of fifteen passes. The rolling parameters (roll gap, roll geometry and

rotational velocity...) for each pass are given. The friction and heat exchange coefficients are then determined by confronting numerical results with experimental measurements carried out on the industrial rolling mill for a first route. The compared results are the rolling torques and the temperature on the surface of the rolled bar. The numerical model is then tested in the case of a second rolling route involving different process parameters.

The validated model is then utilized in order to perform a parametric sensitivity study. The objective of this part is to identify the influence of the process parameters on the shape of the bar, the strain undergone by the material and the non-slipping conditions.

The last part presents the first results concerning the numerical study of the evolution of the microstructure through the Yamanaka criterion for the micro cracks and the Niyama criterion for the porosities. The starting point of this study is the numerical simulation result of the continuous casted products.

As a conclusion, a numerical model of the rolling of bars of large diameter was implemented and validated. It allows the validation of the rolling route and allows following structure criteria from an initial state (cont-casted blooms or ingot) obtained by numerical simulation.

Gas Cleaning / 354

Gas odorization technology for toxic gas leaks detection in the steel industry

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During the steel making process, huge quantities of gas are produced, stored and used as fuel later on in the process. It is the case of the Coke Oven Gas (COG), the Blast Furnace Gas (BFG), the Basic Oxygen Furnace Gas (BOFG) and the Corex Gas. Those gases contains high percentages of Carbon Monoxide (CO), which is very toxic at low concentrations and also odorless and colorless, which makes them undetectable to human beings.

Many accidents occurred every year due to CO leaks. Even though many safety measures has been put in place, according to the world steel association, gas and asphyxiation is one of the five main causes of fatality in the steel industry.

Gas Odorization is a proven technology, used globally for the distribution of Natural Gas and Liquefied Petrol Gases (LPG), which are highly explosive, just by adding a warning agent that makes them detectable in case of leak. Over the past decades, Arkema has developed a strong expertise in this field and enjoy today a leading position for the production and supply of gas odorants.

This technical paper explains the basis of gas odorization technology as well as its implementation for the toxic gas detection in the steel plants.

Rolling / 355

Topographic surface inspection system for slabs

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3D-Measurements for slabs and heavy plate are now available and close the gap in the production chain. The measuring systems described in this presentation must be seen as high-tech solutions in the field of casting and rolling technology. The measuring systems were developed taking into consideration the harsh casting and rolling mill environment in which they are to be used, with the aim of achieving high operational reliability and eliminating disturbances. Interconnected quality management systems enable optimization across the complete production process. New limits are being defined constantly for all these developments. What is technically feasible today

becomes normal practice tomorrow, and will probably be replaced by completely new technologies the day after.

Electric Arc Furnace / 356

Activities for EAF Process Improvement to Acciaierie di Calvisano including KPI's approach for process monitoring and implementation of lime injection

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The EAF process reach different results during the different production periods depending by variabilities in operating practices applied, equipment's efficiencies, scraps charged and hot heel present. A mathematical tool for continuous monitoring of process performances and technological phenomena in EAF has been developed in collaboration between Feralpi Group and CSM to monitor steel/slag composition and temperature and also slag foaming effectiveness, energy losses, energy efficiency. This approach has been used to evaluate the effectiveness of the new system for lime injection implemented in Acciaierie di Calvisano and to improve the necessary injection management to optimize process performances and final results of the application.

Electric Arc Furnace / 357

Activities for through process modelling and monitoring of steelmaking process to estimate and improve process performances and steel qualities

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The experiences to optimize and control the single steps of steelmaking process as EAF LF and continuous casting has shown that a through process approach is necessary to take into account the previous and subsequent process steps as constrains for optimization. In this way Feralpi Siderurgica has developed a new approach of through process modelling and monitoring coupling simulation devices, process monitoring based on KPI's and trials of process improvement with the scope to gain more experience in these activities and improve continuously their process efficiency and steel quality. In particular steel temperature prevision through process along the production cycle has been developed with the scope to let available for the operators the indication of time available for the treatments and guidelines for process management to be followed in case of variations in the normal production cycle as for EAF tapping, casting speed LF sample results. This approach also devoted to improve operating practices in EAF process.

Blast Furnace Ironmaking / 358

Identifying the blast furnace salamander position by using non-destructive testing (NDT) techniques

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In iron making dialogue, a salamander is referred to all liquid and solidified materials in the hearth of a blast furnace which cannot be removed through the taphole. Taphole locations are designed in a way that a pool or sump of liquid hot metal remains in the bottom of the hearth. The resulting salamander has multi purposes. Primarily it provides a buffer to retard bottom refractory wear, acts as a thermal reserve to smooth process swings, and can aid in the control of hearth wall wear through preferential liquid flow patterns in the hearth bottom. Over the course of a campaign, the hearth bottom wears and the final salamander size prior to relining is normally substantially larger than the original design.

Plenary Session / 359

Pioneering technologies to optimize the assets of steel producers

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In 2015, Mitsubishi-Hitachi Metals Machinery and Siemens VAI Metals Technologies established a new joint-venture company for the metals industry under the name Primetals Technologies. As one of its strategic core values, Primetals Technologies tackles the challenges faced by the metals industry that include raw-material price and quality volatility, excess steel capacity that has an impact on steel prices, tighter environmental legislation as well as an accelerated shift to high-value and high-margin steel products. In this scenario, Primetals Technologies is an innovation-oriented company with the clear goal to improve production processes and the assets of steel producers. Most steels are still manufactured on the basis of traditional process steps that comprise the reduction and smelting of ores, and the casting and rolling of solidified slabs, blooms and billets. However, new installations and plant modernizations will be characterized by resource efficiency with respect to raw materials, yield, energy, space requirements, materials, production wastes and water consumption. Examples of substantial benefits that can be gained by an adequate investment strategy for asset improvements will be presented in the iron- and steelmaking area as well as for casting and rolling processes. In addition to electrics and automation, metallurgical services also play a decisive role in value creation and asset optimization, especially with consideration to the driving forces of digitalization and Industry 4.0. Strong partnerships between producers and plant builders are a prerequisite to tackle the current challenges in the metals industry. The technologies developed by plant builders or in partnerships with producers lead to lower operating expenses (Opex), competitive prices (Capex) and substantial revenue gains through the sustainable production of value-added products.

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Refractories 4.0

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

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Digitalization in the steel industry

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Initiative Carbon2Chem

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Political conditions for sustainable innovations in steel

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Environment - climate - energy: Quo vadis industry?

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Opening Session

Oxygen Steelmaking / 366

Optimization of ferroalloy use in the BOF process using machine learning methods

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There is one challenge known to all metallurgists: how much of each ferroalloy to add during steelmaking process in order to ensure the required chemistry of the steel at the lowest possible cost. As ferroalloys participate in numerous chemical reactions, the final absorption of the added elements depends on many factors, which measurements are rough or even unknown. The decision on the exact amount of ferroalloys to be added often relies on a combination of knowledge-based models and expert judgement of the operator, leading to many suboptimal results.

Machine learning is a novel approach that allows to consistently increase the quality of decision-making, resulting in a decrease in the overall ferroalloy use without deterioration in the quality of the resulting product. The proposed solution consists of two parts: (1) the ferroalloy absorption model. Trained on available historical data on previous smeltings at a given plant, this model takes all available parameters – the mass of scrap and crude iron, results of chemical analyses, amounts of the added ferroalloys, and predicts the expected chemical composition of steel. Use of machine learning techniques allows forecasting the deviations of traditional physics-based models, and significantly increases the accuracy of prognosis. (2) optimization module. The module recommends the amounts of ferroalloys required to produce a specific steel grade at the lowest possible cost, while maximizing the confidence of meeting chemical composition requirements.

The pilot tests in a production environment have demonstrated that the use of machine learning-based recommender system allows decreasing the use of ferroalloys by up to 5%, while confidently meeting quality requirements for a specific steel grade.

Industry 4.0 / 367

Machine intelligence for meltshop 4.0

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The purpose of this document is to describe the new technology developed increase the safety, reduce the manpower needed in dangerous areas, increase the traceability and reduce the risk of mistakes in the production. The integration, made in different steps, both in automation and robotics side introduce the concept of the industry 4.0, the digitalization of the information shared with the existent automation and the efficient and friendly interface allow to increase the productivity and reduce the human presence out of the control pulpit.

Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 368

Overview on DissTec project and introduction into topic "Measurement technologies in Secondary Metallurgy"

Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 369

SecMet Measurement technologies in ECSC and RFCS research projects - an overview

Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 370

Measuring of liquid steel temperature in secondary metallurgy

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Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 371

Online Measurement of dissolved gasses in secondary metallurgy

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Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 372

Fast analysis of slag chemistry during secondary metallurgy

Measurement technologies in Secondary metallurgy - Dissemination of results from European research projects (DissTec) / 373

On-line measurement of steel cleanness using rapid inclusion characterisation techniques

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voestalpine Steel Research Award 2017

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