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New developments in mold flow control / 0

Continuous casting mold goes digital. . .

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In modern manufacturing, which aims at maximum productivity and quality assurance, it is essential to make use of high-grade materials, a well thought-out design, the latest coating techniques and intelligent sensor technology.
System solutions that utilize new sensor technologies with “Industry 4.0” in mind open up a wide range of possibilities also in the field of continuous casting. Intelligent mold plate management, for example, allows downtimes to be reduced, service lives to be increased and new, individually detailed logistics concepts to be established. Process integration and digitalization of the mold enable new business models to be introduced, which are likewise digitalized. In future, maintenance will no longer require large-scale and expensive storage facilities. Instead, stock-keeping will become faster and more transparent. Spare parts will be delivered in near-real time after the manufacturer has been informed online about the current degree of wear, likewise in near-real time.
The operating hours and the wear on the individual plates are monitored in a continuous and fully automated manner and logged for subsequent evaluation. The system does not require any external power supply or other cabling. The data are exchanged, logged and evaluated by means of Android-based devices.
The user also has the possibility of commenting on the individual servicing steps and of storing them electronically in the system. Via this digital combination of automated data generation and human-machine interface, a comprehensive process overview is obtained for various business areas such as purchasing, production, maintenance and controlling. This results in advantages and synergies for improved planning and logistics, greater flexibility and quality in production and an immediate overall view of the condition of the mold plate as a core component and of the conditioning work being performed on it. Moreover, improved cooperation with the supplier industry is achieved thanks to the near-real time communication.

Surface defects / 2

An investigation of precipitation in continuous steel slab with the help of dissolution technology

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For the casting of Nb-mikroalloyed steels with C- content >0.09 mass-% the transverse crack formation on the slab surface is a big problem. The production practice at voestalpine shows that these crack formation is dependent on the content of microlalloyed elements like Nb, Al, B, V and N -content. Higher content of micro alloyed element causes more crack formation. In the present work, precipitation behavior like Nb(C,N) , B(N) and AlN in Nb-alloyed steel slabs has been systematically investigated with the help of the dissolution technology which is developed at voestalpine. The Investigation shows that the distribution of precipitate in slabs is different from broad side to narrow side, from slab surface to slab center. The influence of steel composition on the precipitation is identified. In order to understand the precipitation behavior, the numerical simulation was applied to understand the precipitation mechanism, especially about distribution of the precipitate in the casting slab.

Slab casting / 3

ArcelorMittal Tubarão production increase through continuous casting improvements

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ArcelorMittal Tubarão (AMT) is located in the State of Espírito Santo, southeast of Brazil. AMT has been in operation since November of 1983, and its main products are steel slabs and hot rolled coils.
By using continuous improvement in the production process, maintenance and the latest technologies and equipment, AMT is aiming to increase the production of liquid steel at its steelmaking plant in order to reach a stable production level of 7.5 million tons/year of slabs and coils. To achieve this objective, new equipment were installed such as one blast furnace, one BOF, one RH, one KR process and a new continuous casting machine with a nominal capacity of 3.0 million tons/year. Besides the installation of these equipment, some continuous casting improvements were performed.
This paper describes the main features that have been contributed for the casting operational improvements, emphasizing the revamping of continuous casting #1, new procedures aiming prevention of alumina adhesion on submerged entry nozzle (SEN) and upper nozzle, actions adopted to reduce the frequency of breakouts, deployment of submerged entry nozzle quick change system, as well as the increase of SEN life, the decreasing in the frequency of sticker alarm and the increasing of segment life.

New developments / 4

Cooling behavior in continuous casting with hot-top mold

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Abstract: Mold heat transfer is important to mold life, surface quality, breakouts and many other aspects of the steel continuous-casting process. Based on a series of related investigation, the mold cooling process on continuous casting slab of high-carbon steel (wC>1.5%) was investigated. Thermodynamic calculation has been carried out on a high-carbon steel by means of Thermo-Calc program. High-temperature tensile tests performed on slab samples was conducted. The result showed that the liquidus and corresponding pouring temperature of high-carbon steel were ˜100 oC lower than low-carbon steel, and the high-carbon steel exhibited a wider brittle temperature range immediately after solidification compared with those of low-carbon steel. It is difficult to form a stable liquid flux near the meniscus within a short time at initial stage of casting. The slab samples were observed in situ using confocal laser scanning microscopy (CLSM) in order to simulate various mold cooling process. The result illustrated that homogeneity of initial solidification with mild cooling process in the mold should be improved to reduce the concentration of high-carbon slab surface defects. A hot-top mold, which has a significant effect on heat transfer in continuous casting, has been applied on the present study. Low heat conduction coefficient material that can increase heat resistant and decrease heat flux was coated on hot face of mold in vicinity of meniscus. A heat flux and shell thickness in continuous casting predicted on the basis of an inverse mathematic model were conducted. The temperature of shell rises 10˜15 oC with added 1 mm coating on mold by numerical simulation. In plant trial, the temperatures of

hot-top mold monitored by thermocouples decrease 5˜15 oC with hot-top mold compared with the original mold, as well as the temperature difference of mold cooling water that means average heat fluxes decreases, then the homogeneity of heat transfer and slab surface quality improve.
Keywords: Mold Cooling Process; Hot-top Mold; High-carbon Steel; Continuous Casting

New developments in secondary cooling / 6

DynaJet Flex – Ultimate flexibility in secondary cooling

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Cooling Zones at casting machines are typically equipped with air-mist nozzles to guarantee a wide turn down ratio (typically 1:9) from highest to lowest water flow at a constant spray pattern. To prevent corner cracks the Zones are additionally split into center and margin strips across the casting width.
Primetals Technologies DynaJet Flex is the new cooling system to bring the discretization of cooling zones at casting machines to the next level. By using water only nozzles, which are able to be driven with a pulse width modulated signal, it is possible to extend the turn down ratio from 1:9 to 1:15 and higher and save more than 70% of the operational costs by less air consumption compared to conventional air-mist nozzles.
The system can be installed and tested on a segment during a planned maintenance cycle. After reinserting the segment into the machine the air for controlling the nozzles is activated. From this time the segment is ready to operate dependent from casting width to guarantee the optimal temperature of slab in and across casting direction. The DynaJet Flex nozzle design has a robust standard flange, where the nozzle is fixed inside the machine. Every available nozzle tip can be mounted on the nozzle head to realize the required spray pattern.
This paper shows how a caster is modernized with these nozzles, how the productivity of a caster is increased and how the operations costs are reduced.

Thin slab casting / 8

Arvedi ESP's caster skills to enter a new world of endless production

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Thin slab casting and rolling processes are well known and are permanently developed further since their introduction end of last century. Finding the optimum constellation to also economically operate and fully load the rolling mill part lead to different concepts, combining up to three casting strands to be fed into one rolling mill section. These different concepts are based on complex furnace constructions having numerous drawbacks. The key to simplify all these concepts is to reduce to a one strand concept. The basis therefore is a stable and high mass flow. The Arvedi ESP technology represents the benchmark technology in this field, reaching an mass flow leading to annual productions up to 3 Mt/a, allowed by the fully endless operation and several other technological highlights implemented at ESP casting machines. To give an insight, this paper is characterizing the advanced mold system including mold monitoring and mold level stabilizing systems.

Casting of large blooms / 9

Semi-continuous casting technology – Combining technological advantages of two different casting practices

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Continuous casting with bow type as well as vertical machines achieves high productivity and yield at high casting speeds. Nevertheless the speed is limited by metallurgical machine length and required cooling rates to achieve continuous production. This high cooling rates cause pronounced radial orientation of the crystallization front in the strand. Thus particularly at special high alloyed steel grades the strand center gets sensitive for higher porosity and segregation.
In comparison conventional ingot casting has low productivity and yield operating at low cooling rates.
These low cooling rates cause an axial orientation of the crystallization front in the strand and lead to best inner quality at special high alloyed steel grades.
The objective of the Primetals Technologies Semi Continuous Casting technology is the combination of the benefits of ingot casting and continuous casting for production of most special grades like tool-, die steels and stainless steels with improved quality like core tight bloom structure, minimization of center cracks and highest cleanness together with optimized yield. This is achieved by using technological key points like mold and oscillator of conventional continuous casting for optimum surface quality and minimized OPEX, dynamic heat shielding and hot topping for slowest cooling rates in combination with dynamic strand stirring and advanced process models like DynaPhase and Dynacs 3D for dynamically controlled cooling to achieve excellent inner quality.
This paper will discuss different concepts of semi-continuous casting machines for small and big sections showing benefits in quality, yield, operation, investment and running costs compared to continuous as well as ingot casting processes.

Mold level control mold oscillation / 10

Unsteady bulging compensation at Outokumpu Tornio Caster 1 and 2 – Stable meniscus during casting of ferritic stainless steel

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Process stability during continuous casting is an essential criterion for the production of high quality stainless steels. In particular the meniscus, which is the most sensitive zone of the whole strand, has to be in a steady shape and position. As the liquid core of the strand acts like a hydraulic hose, each radial movement of the strand shell is inducing a feedback on the mold level position. Hence unsteady bulging of the shell between the containment rollers is a coupled effect of the transient strand volume and meniscus position. The crucial point for this effect is that the mold level fluctuations are interacting with the generated shell in terms of thickness variations. Ferritic stainless steel grades, which show a very soft and creeping material behavior during casting, are known for their high unsteady bulging affinity.
Also the roller geometry of a casting machine is influencing the unsteady bulging behavior. For instance many consecutive identical roller pitches lead to a superposition of the pumping effects of the roller pairs and an increased bulging affinity. Therefore state of the art slab casting machines

have desired variations of the consecutive roller pitches in the caster segments. Slab casters with a single unit casting bow have staggered rollers between inner and outer bow due to the difference in the number of rollers. The offset between inner and outer bow rollers is reducing the bulging affinity of this machine type.
At Outokumpu Tornio both machine types – segmented casting bow (caster 2) and single unit casting bow (caster 1) – are in operation. For both machines the meniscus stability has been significantly improved by the installation of an unsteady bulging compensation controller, which is suppressing periodical mold level fluctuations generated by unsteady bulging. This model based controller is realized as an add-on software package in the mold level control PLC (LevCon package).

Slab casting / 11

Maintenance of continuous casters for high product quality: Simple measures and advanced tools

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The modern continuous casting machine is a highly complex mechatronic system where utmost precision has to be reached to ensure high product quality while the equipment has to be designed to withstand the harsh environmental conditions. These two requirements alone would make things difficult, but additionally the lowest operation costs have to be achieved to survive under highly competitive market conditions.
During operation of a continuous casting plant, one key to reach high product quality at low cost are good maintenance procedures. The design of the whole equipment should be optimized for maintenance. One example is the newly developed SRD segment where a highly complex system has been designed from scratch with a focus on high maintenance friendliness. The feature of single roller unit exchange should further improve plant availability.
Modern technologies subsumed under the buzzword “Industry 4.0” are used for improving maintenance procedures. Examples are an intelligent equipment tracking system, an automatic test procedure and to smarten up equipment by saving data on the equipment.
So the combination of maintenance friendly mechanic, proper maintenance workshop concept, automated test procedures with built in quality checks and proper reinstallation in the machine will finally improve the reached product quality and reduce the operational cost.
In this paper, several examples are given how components of continuous casters can be exchanged quickly, checked for problems, repaired and tested and brought back to the machine. Additionally examples are given where with technology consulting the performance of a plant could be improved.

Numerical simulation II / 12

Hot tearing prediction during casting of steel through thermomechanical simulation: Comparison with laboratory and semi-industrial experiment

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Hot tearing is a regular defect that affects slab internal soundness. Hot tears form at the end of solidification, typically between 0.8 and 1 solid fraction, when steel exhibits low ductility but can be subjected to stresses which generate deformation. Excessive deformation will then open the dendritic structure and lead to cracks. New steel grades which are currently under development are sensitive to hot tears. Predicting hot tear is thus of primary interest for steelmaker in order to identify key process parameters which lead to hot tears and study level of these parameters. The aim of this study is to evaluate hot tears risks through thermomechanical simulations coupled with computation of an internal crack criterion. Simulations are done with Thercast® software 1 and the internal crack criterion used is a mechanical based criterion (Won criterion 2). It predicts internal cracks if the cumulated tension strain is higher a critical strain. A good agreement is obtained between the thermomechanical simulation predictions and the experimental results for two configurations: classical bending test and semi-industrial continuous casting pilot trial with reheating to promote internal cracks.

1 O. Jaouen, F. Costes and P. Lasne, "Finite element thermo-mechanical simulation of steel making from solidification to the first forming operation", Metec InSteelCon, Düsseldorf (2011).
2 YM. Won, TJ. Yeo, DJ. Deol, KH. Oh, "A new criterion for internal crack formation in continuously cast steels", Metallurgical and Materials Transactions B, Volume 31B, 2000, p779-794.

Surface defects in slab casting / 13

Chamfer mold technology for corner cracks reduction: Understanding and design optimization through numerical simulation

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Corner crack is one of the main defects which affects continuous casting slabs. It downgrades slab surface quality and requires further scarfing which is costly and time consuming. Chamfer mold technology is a new mold design which may reduce corner cracks occurrence during continuous casting process. Conventional continuous slab casting uses rectangular shape mold with 90°corners. Chamfer continuous casting mold exhibits a rectangular shape but with chamfer corners. Assessment of this chamfer mold concerning corner cracks occurrence is done thanks to numerical simulation with a 3D thermomechanical finite element software called Thercast®. A comparison between conventional and chamfer mold simulations is done in terms of stress and temperature distribution in slab corners. Results show that chamfer corners lead to an increase of temperature and a decrease of stress at corners which may effectively decrease corner cracks occurrence. In a second step, the influence of chamfer geometry parameters (angle and length) on stress and temperature distribution is investigated and discussed.

Bloom casting: New concepts and operational practise / 15

Latest innovations in bloom casting at Hyundai Steel Dangjin

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This paper provides an overview about latest realized solution for the bloom continuous casters on the example of a heavy section bow type caster, which is equipped with latest technological packages. Bars and wires, which are rolled out of the blooms, serve as primary material for engine and gearbox parts for Hyundai Motors Group.
The caster is equipped with latest mold-level control and an instrumented mold featuring breakout prevention. In combination with air mist spray cooling and interior-cooled rollers in the strand guidance system, DynaGap Soft Reduction, Mold, as well as, Final Electro-Magnetic Stirrer, ensure uniformly high quality of the cast blooms. Still hot, these are then fed for direct use in the bar line. This saves energy during reheating and improves operating safety because there is no need for handling of blooms by cranes. For special grades an inline bloom quenching facility is foreseen.
This paper gives an overview about the bloom quality results achieved during the startup of continuous casting machine installed for Hyundai Steel at its Dangjin works.

Soft reduction / 16

CCM 4.0 – digitalization for intelligent production in continuous casting

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The digital transformation achieves a structural change in automation – a transformation of process automation into a new and more efficient structure. Today's hierarchical automation pyramid is replaced by a flat structure of intelligent, flexible and autonomous units. It is important that the metal industry makes an active contribution to implement digitalization in their production plants throughout the entire value chain.
Digitalization for intelligent production synchronizes process-, machine-, and product-data for integration with business data in a "Smart Factory". "Smart Services" enable data based services for example predictive / data analytics. Smart Work provides assistance in maintenance and operation. Smart examples for the caster area are given in this paper.
The next generation of model-based process automation control is to link the real plant with the virtual plant in a so called "Cyber-Physical System". This is done by modelling and simulation of the casting process for example by integration of material properties according to the actual composition, strand surface temperature profiles and dynamic soft reduction before the final point of solidification. The aim of the digital transformation and crosslinking of production provides high flexibility and efficiency in production, high plant availability and high product quality.
Primetals Technologies is committed to digitalization and to realize the connected plant by continuously pushing latest innovations in automation in a close cooperation with customers.

New developments / 17

Rolling technologies for the direct strip casting process

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The direct strip casting process has attracted attention as a near net shape technologies. BAOSTEEL GROUP CORPORATION and Primetals Technologies Japan, Ltd. have jointly developed

technologies for the direct strip casting process of carbon steel. The demo plant for the direct strip casting process, with 800 mm diameter and 1340 mm long casting rolls, was installed in China and its operation was started up in 2014. A stable casting and rolling of 1340 mm wide strips and long term sequence casting of more than 350 ton were succeeded. This paper presents specific technologies for the downstream equipment of the direct strip casting process such as an in-line reduction mill, strip cooling system and carrousel reel type coiler. Our discussion focuses on stable rolling technologies including technologies of the Dynamic Pair Cross Mill and strip temperature control.

Slab casting / 18

Advanced mold copper plating - Variable hiper coating

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At Primetals Technologies Brazil Ltda. Rio de Janeiro Santa Cruz Workshop we electroplate mold coppers for continuous casting by tank plating. Tank plating submerges the copper in the bath of the plating solution. This is the most common method of plating and is applicable for both broad-face and narrow-face copper plates. Mold copper plates have a decisive impact on the product quality as well as the cost for maintenance and production. A perfect understanding of the operational influences on the plates and performance variables are the first step for the right selection of a copper plating method. Variable Hiper Coat keeps the Copper Plates 50% up to 100% longer in operation because of applying hardness on the Copper Plate where it is needed. Primetals Technologies Brazil provides the solution which meets and exceeds the requirements for todays and future demands.

New developments / 19

Development and industrialization of strip casting technology in Baosteel

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Abstract
China's first twin-roll strip casting demonstration industrial plant (NBS Project) with strip width of 1340 mm was built in 2014 by Baosteel in Ningbo, China. After a year of commissioning, the demo plant was put into stable casting and rolling production in 2015. The longest continuous casting time reached 4h and a thickness of 0.9mm ultra-thin carbon steel strip was produced successfully. This paper describes development of strip casting technology by Baosteel, and technical specifications of the strip caster at the demo plant. Discussion focuses on several specific equipment, such as casting roll with long service life, and the device for rapidly changing casting roll.

High speed billet casting / 21

High speed casting and the innovative WinLink Mini Mill at GPH Bangladesh

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WinLink is a pioneering technology from Primetals Technologies that allows both endless and semi-endless production of long products from liquid steel without interruption.
The solution directly links a high-speed billet caster to a high availability rolling mill by using an advanced induction heating unit instead of conventional billet reheating furnace.
GPH Ispat Ltd. in Chittagong / Bangladesh is the first client where Primetals will implement the WinLink solution providing the full flexibility to run the plant in various production modes. One strand of the 3-strand Win Link billet caster is linked directly to the rolling mill in endless mode where up to 70 tph rolled products can be produced at casting speeds of about 6 m/min without cutting and heat loss.
The two additional billet strands are used for the production of about 50 tph saleable billets which are transported over the cooling bed and to be rolled on GPHs existing rolling mill. This multi-strand configuration significantly improves the productivity of the plant by providing better flexibility in unpredictable market changes.
The paper will provide an overview of different profitable WinLink variants which are offered for production of capacities up to 750.000 t/a of rolled products and presents the implemented technologies to enable high speed casting up to 6 m/min at the GPH billet CCM.

Slab casting / 22

HKM operation results: Effective use of PT process models

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In May 2015 the modernized slab caster No. 3 in Hüttenwerke Krupp Mannesmann GmbH (HKM) Duisburg-Huckingen plant in Germany went into operation. The revamp was done by Primetals Technologies Austria, with the targets of enhancing quality and product tolerances of the slabs produced, widening the product portfolio, and improving process stability, availability, and workplace safety. For reaching these goals the latest PT process models had been in use excessively. Additionally the basic and process automation as well as the upgraded safety equipment was renewed completely either. To mention are here that new implemented models and technological packages like DynaPhase, the DynaGap Soft Reduction, Dynacs 3D, LevCon, DynaWidth, and DynaFlex. In combination with the air-mist secondary cooling system, which also had been renewed, the new surface temperature control ensures a continuous production of high-quality slabs. Due to the used process models as well as the new technological packages it was possible to reach the required quality level of the slabs already from the first heats on.
This paper describes the course of the project, how the plant structure was modified, redundancies were installed, and the plant's functionality had been extended. This revamp led to increased availability, extended product portfolio and optimized yield of the produced slabs. Beside the improved process stability and quality level, also occupational health and safety at slab caster No. 3 had been improved. A selection of long term quality improvements and quality optimizations are included in this paper.

Operational practises in billet casting / 23

Technological solutions for the revamp of long product casters

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Primetals Technologies provides proper technological solutions for the revamp of long product casters, and the most recent examples for successful implementation at Feralpi (EFS) and at Abinsk (AEMZ) are presented in this paper, showing the qualitative results that can be achieved within shortest project execution time.
Elbe-Stahlwerke Feralpi (EFS) in Riesa, Germany awarded PT with a contract for the modernization of the five strand billet caster in the Riesa works in Germany and the plant started operation in 2015. The aim of the project was to increase productivity and to further improve the internal as well as the surface quality of the billets. The caster was equipped with a new machine head, including DiaMold mold tubes and retractable DynaFlex hydraulic oscillators and also the secondary cooling was upgraded. In order to optimize the shutdown period the new equipment was pre-assembled and tested to keep the installation time at a minimum.
OOO Abinsk Electrometallurgical Plant (AEMZ) is one of Russia's leading producers of reinforcing bars and other long products and runs an electrical steel plant and two rolling mills in Abinsk, located in Krasnodar region (South Russia).
PT was awarded with this contract in March 2016 to revamp the EAF, LF and 6 strand billet CCM and the main goals are increase of productivity, reduction of production costs, improvement of billet quality and widening the production program by producing quality steel grades like cord, spring, cold heading and welding grades.
Casting speeds will be increased up to 5 m/min for square section 130 mm to enable AEMZ to increase the plant annual production up to 1.5 Mill t billets. For casting quality steel grades stopper casting equipment, electromagnetic stirring system, tundish shroud manipulators and automatic mold powder feeders will be installed. The new machine head consisting of DiaMold high speed casting mold, DynaFlex hydraulic oscillation unit and mold EMS ensures high quality of cast billets.
The new level 2 automation system ensures consistent production practice for production of high quality billets cast at high casting speeds.

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Study on spray cooling for voestalpine CC4 slab caster

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The dual strand casting machine CC No.4 at Linz steel plant is the eldest machine in operation and casts 215 mm thick slabs of ultra-low carbon, low carbon and HSLA steel. Recently bothering sliver defects appeared on the hot bands in a certain width range of approx. 1000 to 1200 mm when casting micro-alloyed construction steel. Such defects were not seen on hot band when rolling slabs from the other casting machines in the plant.
Primetals Technologies did a comprehensive study work on the entire air-mist spray cooling in cooperation with voestalpine experts. The cooling setup and operational adjustment was reviewed. Spray performance of each used nozzle was checked in PT test facility and water distribution across slab width was created by simulation tools. By this, realistic spray pattern for each cooling loop as well accumulated patterns at certain decisive positions were established and constructively reviewed. Exceptional situation with collision of sprays with neighboring equipment were considered in the nozzle tests and simulations.
Critical situations and items leading in local overcooling were recognized and was brought in relation to the above mentioned quality issues. A stepwise plan for improvements was developed. Most of dominant product quality drawbacks were resolved after implementation of first short-term modifications. Currently the medium-term modifications are in preparation.

Mold level control mold oscillation / 25

Implementation of silicon based photomultiplier technology for radiometric sensors for mould level measurement

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For decades most radiometric sensors have been based on photomultiplier tube technology. Berthold Technologies GmbH has lately implemented the new silicon photomultiplier technology in radiometric sensors for mould level measurement. By multiple silicon based photomultiplier chips in an array, numerous benefits have be achieved. The strong temperature dependency of the silicon photomultipliers is used to completely compensate for any aging of the scintillator and for any changes in the optical coupling. The new technology does also provide full immunity against electromagnetic influences from electromagnetic brakes or electromagnetic stirrers, and a drastically increased overall robustness. One new sensor design has e.g. been tested to endure 2 m drop tests. Also the now possible smaller form factor has enabled new ways of sensor design. One of the possibility exercised, was to design a compact sensing modules consisting of a single scintillator and a matrix of silicon photomultipliers. Such modules have then been stacked in a sensor arrangement up to eleven modules conveying simultaneously dual-phase (steel and powder) measurement capability. Other significant improvements with silicon based photomultipliers are the increased detection efficiency, the more than ten times decreased bias voltage, automatic noise detection, and the preservation of the photon energy that enables advanced spectrum analysis. The achieved improvements significantly increase product life-span, decrease life cycle cost for the end users, and enhance measurement possibility and accuracy.

Bloom casting: New concepts and operational practise / 27

Operation results of vertical casting of heavy round blooms at Zhong Yuan Special Steel

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A new vertical caster for special steel grades was started up at Zhongyuan Special Steel Co., Ltd., in Jiyuan, China in June 2015. The 2-strand vertical round bloom continuous caster has a capacity of up to 370,000 metric tons per year, which enables Zhongyuan to produce additional high-quality steel grades, since the company only had an ingot casting plant for the production of mainly steel forgings. A newly designed multi-roller driver unit ensures optimum support of the 120-ton strand during casting. This is the first plant of its type, worldwide. The new continuous caster is designed as a vertical plant with a height of 40 meters and a metallurgical length of 23 meters. It produces heavy blooms with diameters of 400, 600 and 800 millimeters and lengths of between 2.5 and 6 meters. The casting speed is up to 0.55 m/min. The caster is equipped with a straight SIMETAL DiaMold tubular mold that is 700 mm long. The SIMETAL DynaFlex tubular mold oscillator helps to provide flexible adjustment of the oscillation parameters. Technology packages such as the SIMETAL LevCon casting level control system and the SIMETAL Mold Expert breakout detection system ensure trouble-free casting. An advanced air mist secondary cooling system, including the SIMETAL Dynacs 3D metallurgical cooling model and the SIMETAL DynaJet cooling nozzles ensure optimum quality. The latest solution for heavy-bloom round casting and the corresponding operational results are presented to demonstrate the special features of vertical bloom casting.

Tundish / 28

LiquiRob – Next level shroud manipulation – from an idea to an industrial solution in 3 major steps

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The paper will explain how to successfully implement a robotic solution from the initial idea to a working industrial solution. Primetals Technologies could call upon the past 10 years of experience in installation of Robot solutions in the harsh environment of steelmaking plants - the so called LiquiRob. To enhance an existing shroud manipulation system, the idea to connect the shroud with a bayonet mechanism to the ladle nozzle was born, due to the requirements of a well-known steel producer. The paper will describe the development steps from the first simulations and prototype testing in the laboratory, it will show the intensive system testing under workshop condition and finally the successful integration into the plant. Further the operational experience will be shown as well as the advantages of such an installation compared with other shroud manipulation systems.

Numerical simulation I / 30

Coupled fluid dynamic and electromagnetic calculation of mold and secondary cooling region in a continuous caster

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In continuous casting of ferritic stainless steel electromagnetic stirring (EMS) is a common approach to generate an equiaxed crystal zone as large as possible. The layout of the electromagnetic device directly affects the intended solidification structure in the strand. In order to predict this influence, SMS group has developed a numerical model to simulate the interaction between flow field, solidified shell and electromagnetic field in the caster.
The transient melt flow (SEN, mold, strand) is solved with a numerical tool based on the open source library OpenFOAM. In order to consider turbulence phenomena, a hybrid large-eddy turbulence model has been used in addition to the Magnetohydrodynamic (MHD) equations which are solved time-dependent in a fully coupled manner in the strand. The magnetic fields induced by the stirring coils are calculated by ANSYS EMAG.
In the present case the influence of different stirring concepts on the flow and temperature distribution in the strand has been investigated. It is shown that the stirrer geometry - with same amperage in the stirring coils - has a significant impact on the induced magnetic flux density and thus on the stirring behavior. Based on the calculated temperature distribution and solidification rate the solidification structure in the strand has been calculated by a corresponding microstructural model.

Slab casting / 32

PQA-the successfactor to reach next performance level in continuous casting

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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 and points out the customer benefits, cost reduction, improvement yield, customer satisfaction increase.
The link to recent operational references are given.

Mold level control mold oscillation / 33

Mold Level Scanning, a new tool to characterize steel flows in mold

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Steel meniscus fluctuations and level deformations in CC mold are one cause of the defect occurrence on slabs and later on coils. Slivers, which are one of the most costly defects observed on coils, are partly due to slag entrapment in CC mold. Actually, a strongly deformed meniscus and sudden meniscus level fluctuations favor the slag carry-away into the steel and entrapment of slag droplets in the solidifying shell in mold. Process parameters (such as mold width, casting speed, argon flow rate ...) or events (such as clogging, breakout alarms ...) impact directly steel flows in mold through the meniscus velocity and the flow pattern but through the meniscus deformation and steel level fluctuations as well. Following these last data would enable to better understand what happens in the mold and to act efficiently to improve the product quality. ArcelorMittal Research and Vesuvius developed a tool to measure on-line the steel level along half of the mold width. The device is composed of a robotized manipulator arm which insures the translation/rotation movements of an Eddy-current head, similar to the one used for mold level control. The first prototype was installed on an ArcelorMittal caster. The equipment is fixed on the tundish car and can operate just after the sequence start-up. Measurement campaigns showed the impact of casting parameters on the meniscus deformation. Position of "waves" actually depends on the mold width and the casting speed. It was also noticed that the intensity of level fluctuations is not constant during casting even if the process parameters are kept constant. This equipment is therefore an interesting and relevant tool to better control the casting process and drastically reduce the mold slag carry-away at meniscus, which could be at origin of many defects such as slivers.

Surface defects in slab casting / 39

Retention characteristics of ultra-low carbon steel slab corner shape and its influence on edge defects of steel strip

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Based on the numerical simulation and industrial experiment research, the retention characteristics of the ultra-low carbon steel slab corner shape in the hot rolling process and its influence on the edge defects are analyzed. Numerical calculation results show that, the chamfered face changes to be circle arc during hot rolling process. The uniformity of stress distribution is improved. The deformation of corners is more stable. That is benefit for controlling edge seam defect. The industrial test results show that chamfered shape can be maintained to the end of rough rolling with the small width reduction. Corner temperature is higher and uniform in rough rolling process. The chamfered shape is also retained after rough rolling, and that is benefit for stable deformation during finish rolling. Thereby the edge seam defect will be eliminated and the possibility of the occurrence of the defect on surface is reduced radically. The statistical results of industrial rolling show that the edge seam defect is effectively controlled by using chamfered slab.

Clean steel and clogging / 40

Precipitation of CaS from CaO-Al2O3 type inclusion

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In some cases, the precipitation of CaS around CaO-Al2O3 inclusions are observed in hot coil, even though it is not found in CC slab. The purpose of this study is to investigate S solubility in solid CaO-Al2O3 at various temperatures and clarify the mechanism of this phenomenon. For the experiment, first, the mixture of the reagent of CaO, Al2O3, CaS at a given composition was charged in Al2O3 or Pt crucible. Then, the CaO-Al2O3-CaS oxides were melted at 1723K in Ar atmosphere. After that, the oxide sample was cooled and kept at around 1173K for 1 hour and quenched. The obtained oxides were analyzed by FE-EPMA. In the sample of 42.2CaO-51.5Al2O3-6.3CaS(mass%), 12CaO[U+FF65]7Al2O3(C12A7), CaO[U+FF65]Al2O3(CA) and CaO[U+FF65]2Al2O3(CA2) were observed and in the sample of 51.5CaO-42.2Al2O3-6.3CaS(mass%), C12A7 and 3CaO[U+FF65]Al2O3(C3A) were observed. In every condition, sulfur content in C12A7 showed extremely high but its content in the other oxides were close to zero. The solubility of sulfur in C12A7 was around 1.2% and was independent on heating temperature. This value was higher than the sulfur solubility in the molten oxide of CaO-Al2O3 just above its melting point. This result indicates that by the control of oxide composition, the precipitation of CaS around the oxide is able to be avoided.

Tundish / 41

Tundish inclusion removal modelling implemented in OpenFOAM

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Non-metallic inclusion have a strong impact on the final product quality in steel production. Thus, inclusion removal from the melt is an important aspect of achieving the intended steel

properties. In continuous casters the tundish can be utilized to enhance inclusion removal. One method to promote inclusion removal within the tundish is the installation of an argon bubble curtain.
The aim of this work was to implement a model for inclusion removal within the CFD framework of OpenFOAM. This model considers agglomeration of non-metallic inclusions as well as argon bubble flotation. A population balance for a finite number of inclusion size-classes is solved to account for the agglomeration of inclusions. Argon bubble flotation is considered in the model likewise.
The open source CFD framework OpenFOAM was chosen for the implementation as it offers the most freedom and flexibility. The bubbly flow within the tundish is modeled by using the Euler-Euler model (two fluid model). The inclusion removal model is implemented in a modular fashion so that it can be easily extended.
In order to demonstrate the model we compare the inclusion removal efficiency of the three cases: pure agglomeration without argon bubbling, pure agglomeration with argon bubbling, and agglomeration and argon bubble flotation. This model offers a tool to investigate the efficiency of argon bubbling on inclusion removal.

Surface defects / 42

Carbon content, solidification and strain energy phenomena affecting hot ductility behavior during continuous casting of microalloy steels

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Micro alloy steels are an important product within the automotive, energy, pipeline and structural segments. Superior continuous cast bloom quality is critical in order to achieve the high quality strength and toughness balance required for today's demanding bar, plate and sheet applications. Continuous casting parameters, such as super heat, mold level fluctuation, heat transfer, fine grain chill zone depth and other process performance parameters directly influence solidification behavior and hence the surface and internal quality of the steel strand. This research identifies that the traditional hot ductility as measured via the percent reduction in area (%RA) at elevated temperature grossly overstates the minimum ductility required to assure crack-free casting of micro alloyed steels. Strain energy measured from industrial heat sample stress and strain curves are a better measure of the hot ductility behavior than %RA. This research describes the poor relationship between %RA prediction and the propensity for slab cracking during the industrial casting of micro alloyed steels. The strain at the ultimate tensile strength exhibits a very high correlation coefficient with strain energy and extremely low correlation coefficient with %RA. The carbon content, fine grain chill zone depth and strain energy directly govern hot ductility behavior and the propensity for crack formation during the unbending phase of the continuous casting process. Elements other than carbon and micro alloys exhibit secondary or tertiary root causes for crack formation.

Surface defects and postprocessing of slabs / 43

Slab milling - Postprocessing of slabs in hot condition

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General Information Slab Milling According to today's state of the art, the continuous casting process is almost entirely used for the production of flat steel material. In the manufacturing process for high-quality rolled products, the requirement especially on the surface quality and homogeneity of slabs has increased significantly in recent years due to the quality and price pressure. A few years ago it was still common to generously recirculate the end pieces of rolled

products into the material cycle but by reasons of economic this is no longer possible. Due to quality and costs, imperfections in the slab now have to be detected at the beginning and have to be removed before further processing in the rolling mill. If this is not done, imperfections show up subsequently in quality problems in the final product. This results in high requirements on the slab manufacturing process and the material quality regarding crack-, kerf- and inclusion-free surface quality. Based on the final product, the energy balance is reflected in the production costs and therefore also in the final product. Because of the discontinuous procedure and the consequence of cooling and heating cycles an increased energy expenditure results. The steel industry is constantly on the lookout for potential energy savings and quality improvement measures in order to represent the overall process and the final product competitive. Each potential savings with the same or even better material quality represents a major competitive advantage in the global world market.
Current status of technology in slab finishing before rolling:
• The requirement for the surface quality of the slab rises highly since defects in the end product cause far higher costs these days. • Slabs are parked after the continuous casting and therefore cool down (energy loss). It can happen that the slabs tear during cooling. • The required processing of the surfaces can only take place at max. 600 ° C (technology milling and scarfing). The grinding method can be carried out at 600 ° C but it is more and more undesirable in this sector due to the high dust levels. • After treatment, the slab needs to be heated again which means considerable energy expenditure. • The surface treatment for the elimination of defects is performed nowadays in practice with o Scarfing and grinding: approx. 80%, Tendency decreasing o Milling: approx. 10%, Tendency increasing o Without treatment: approx. 10% Development beginning of the milling solution at 600 ° C
The company's internal development group of MASCHINENFABRIK LIEZEN focused in 2014 on the new development of a powerful milling machine for slabs with the following objectives:

1. Continuous milling of steel, SS and aluminum slabs at up to 600 ° C with high milling performance
2. Topographic surface recording in order to allow milling adjusted to the slab contour
3. Automatic defect detection on the surface
4. Software for the combined processing of point 2 and 3 to minimize the material removal through modulated milling in one pass at simultaneous fault clearance
5. Reduction of operating personnel
6. High level of safety due to a self-sufficient, fully automated system
7. High performance / flow rate

Details of the development work 1. According to the current state of the art, the slabs have to be cooled to a temperature of around 300 ° C after the casting process, to allow subsequent processing. The aim of the hot working process is that after the casting process the slab (with a temperature of about 600 - 700 ° C) is directly transported to the milling treatment, to process the slab immediately while hot in order to avoid the cooling of the slab. Since the slab doesn't cool down and has not to be heated again to about 600 ° C for further processing in the rolling mills, it results in enormous potential energy savings around several gigajoules per slab based on the large thermal capacity of solid metal blocks (up to 50 tons).
It follows a major cost saving potential because the heating in an oven is no longer necessary. In addition, structural advantages in the manufacturing process arise, thus there is a further significant step forward in quality. The hot processing of slabs therefore represents a unique feature in innovation.
Concerning the milling tools, new replaceable inserts with new geometry have been developed which dissipate the heat faster and are adapted to the altered fracture characteristics of the chips.

1. Topographic surface recording Before milling, the surface of the slab is measured by means of a specially designed laser measuring system to subsequently keep the chip removal as low as possible during milling. This causes a considerable cost saving especially for high-grade steels.

2. Automatic surface defect detection The development of the crack detection respectively the slab surface detection and assessment in hot condition is an innovative step which has a positive effect in process safety and hence on the quality and also on the costs. Currently the detection of defects takes place by visual inspection of employees. Nondestructive-working online devices are not available at continuous casting facilities. The used crack detection is on the one hand intended to declare the points to be processed and on the other hand to remove defects of the slab automatically partially after processing of the slab.

3. Reduction of operating personnel Another apparent desire of the steel industry is the personnel reduction directly on the machine base with respect to possible threats. By increasing the level of automation of this new machine and the fully automated tool changing system, the heads of the worn inserts are automatically exchanged. All this is monitored in the control room. Consequently this milling machine works with only 2 employees (1x control room, 1x crane)

4. High performance / flow rate The machine is equipped with 2 milling heads with each of 250 Kw that secure a material removal of max.12 mm respectively 600.000 year-tonnes.

Description of a typical milling work process Sequence o Complete topographic laser examination (contour), afterwards: o Modulated milling followed by thermographic surface defect detection o During milling: [U+F0A7] Permanent tool breakage monitoring [U+F0A7] 100% Chip recycling o Finishing: Local milling of detected defects

Numerical simulation I / 44

Modelling slag entrainment in the continuous casting mold with LES-VOF simulations and comparison to a water/oil benchmark experiment

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Slag entrainment is a challenging problem to control during continuous casting process. From fluid dynamics viewpoint, it mainly occurs due to (I) the instability of the fluids interfaces at the top of the mold and (II) vortex formation around the sub-merged entry nozzle (SEN). Both mechanisms are complex phenomena involving surface instability, vortex interactions with the metal-slag-air interface, deformation of the slag layer and its entrainment into the molten metal in the form of small droplets.
Numerical modelling is a challenging task due to different physical scales involved in the real process. In this work a large eddy simulation - volume of fluid (LES-VOF) approach is used to investigate the flow behavior upon injection into the mold and the unsteady flow/vortex interaction with the meniscus interface.
In order to validate the numerical simulation a benchmark experiment was designed to investigate the flow field in the proximity of a liquid-liquid interface. The experiment uses water and paraffinum liquidum to model the combination of liquid steel and the slag layer. While the entrainment of oil droplets can be visualized via shadowgraphy the flow field was measured via particle image velocimetry PIV. In combination these two methods allow a qualitative and quantitative comparison of the unsteady flow characteristics with the CFD results.
To quantify the agreement of numerical and experimental results, we compare the findings on different scales, like the global flow behavior, velocity profiles at different inflow conditions and the velocity fluctuations and interface dynamics at the liquid-liquid interface. The general agreement of CFD results and experimental data is very good.

Submerged entry nozzle / 47

Energy saving Monolithic ISO Components for Flow-Control and Clean-Steel

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Monolithic isostatically pressed ceramics for flow-control applications usually consist of 20-30wt% of carbon plus refractory components. The main role of the carbon is to create a thermal shock resistant microstructure in the ceramic body. One negative side effect is it's relatively high thermal conductivity which can lead to temperature losses of the liquid metal on its transfer from ladle to tundish and from tundish to mould.
The temperature loss of the liquid metal requires extra superheat to avoid unwanted solidification and clogging in submerged nozzles. To avoid these effects is key to cast highest quality steels. Some practical examples for ladle shroud and submerged entry nozzle applications with reduced heat transfer achieved by insulation layers manufactured into the refractory body are shown in this work. Measurements in the plant and simulations indicate a potential for energy savings and quality improvements in the steelmaking process.

Submerged entry nozzle / 49

Influence of the free surface oscillation on the SEN flow prediction for the thin slab casting

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In the recent study from the authors 1 a criterion is established for the near wall mesh treatment for simulating submerged entry nozzle (SEN) flows for the industrial applications. Fulfilling the criterion is found to crucial when it concerns a possible flow detachment (see Fig. 1) inside the continuous casting (CC) SEN. A numerical model, based on the RANS approach, matches the water modeling results quite well qualitatively, however a mismatch in the main jet oscillations frequency is detected as well as the magnitude of the submeniscus vortex is not predicted correctly. The possible reasons for the mismatch are (a) the lack of accuracy in the turbulence modelling and (b) exclusion of the free surface from the simulation.
Thereby in the presented study a free surface is included into the numerical model along with a study devoted to different turbulence modelling approaches: (i) Scale Adaptive Simulation (SAS), (ii) Large Eddy Simulation (LES) and (ii) laminar "coarse-DNS" models are compared with the previously used one 1. Additionally the comparison for the wall function approach with the near wall treatment method is done. The results are verified by the water modeling experiment including speed camera recording of the dye injections and the submeniscus velocities measurements.
Keywords: Thin slab, turbulence, RANS, SAS, LES, coarse DNS, wall functions, water model
Literature: 1 A. Vakhrushev, M. Wu, A. Ludwig, T. Holzmann, G. Nitzl, Y. Tang, G. Hackl. Establishing a numerical criterion to verify the RANS-type flow simulation in application to the continuous casting process // ESCO 2016, 5th European Seminar on Computing, June 5 - 10, 2016, Pilsen, Czech Republic

Tundish / 53

Superheat range optimization and evaluation of continuous temperature measurement system in tundish

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Superheat is essential for the continuous casting process. It is the amount of temperature above the Liquidus temperature, which ensures to keep the steel in liquid form until it reaches the mold. Once at the mold the superheat is removed and the steel is allowed to solidify in a controlled manner. If superheat is too high, the steel might not solidify in the mold causing breakouts. If superheat is too low, the steel might solidify prior to reaching the mold causing tundish nozzle choking and cast abort. Therefore, there is an optimum range of superheat temperature for a smooth casting process. Steel plants have a tendency to cast with high superheat, which brings a loss of opportunity. The benefits of lowering the superheat include increasing productivity by casting at higher speeds, reducing the risk of breakouts, improving quality, and energy saving. The objective of this work was to investigate superheat practices at Hadeed, and recommend ways to improve the superheat practice. A trial of Heraeus Electro-Nite is Castemp Continuous Temperature Measurement system for better process control is also explored.

Operational practises in billet casting / 54

Atypical secondary oscillation marks formation with abnormal oscillation settings

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Atypical secondary oscillation marks (SOM), and related transversal surface cracks, have been detected on the billet surface between two consecutive primary oscillation marks, when casting with abnormal oscillation settings in Curve Continuous Casting (CCC). The study of the obtained near surface solidification microstructure under this conditions have shown similarities with the microstructure obtained in the Horizontal Continuous Casting (HCC), where SOM were also frequently observed. The oscillation parameters and the corresponding shell formation of both casting processes have shown close similarities when in the CCC process the movement of the strand relative to the mould is considered. The study of solid shell formation under this perspective gives a new insight in the very beginning of solidification and on the formation oscillation marks mechanism. A study of the equivalence between the HCC extraction parameters and CCC oscillation parameters is carried out, in order to avoid SOM and the formation of hook segregated cracks.

New developments in mold flow control / 55

Mould flow monitoring solution: An on-line tool to characterize flows in CC mould

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Flows in CC mould are a key parameter to control products quality. Mould Flow Monitoring (MFM) is a solution developed by Amepa Company. It is an electromagnetic technique using

sensors implemented behind the copper plate of the mould which consist in permanent magnets and several highly sensitive detectors without direct steel contact. These sensors are able to measure the velocity of liquid steel close to the solidifying shell.The basic measurement principle is a time-of-flight measurement, using the correlation method by calculating the flight time of a velocity perturbation. Assessment of this technique is done thanks to Submeniscus Velocity Control (SVC) sensors developed by ArcelorMittal Maizières R&D. This second technique is based on the use of refractory probe immerged in liquid steel in mould at meniscus which in fact measures torque converted into velocity. The 2 techniques are compared under different casting conditions in an ArcelorMittal steelplant and the agreement between both measurements is very satisfactory. In a second step, Computational Fluid Dynamics simulations applied on the same casting conditions, confirm the correspondence between MFM location, close to the solidified shell, and SVC one, at meniscus, in terms of velocity generated in the mould. All of these agreements confirm that MFM solution is able to measure flows in mould without any contact with liquid steel and without any intervention from operators.

New developments in mold flow control / 56

Study of the interaction between slag and cast alloy at meniscus and mold contact in continuous casting process with a 3D multi-physics fluid/stucture numerical simulation model

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It is well known now that the cast product 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 exit from the SEN 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, slag that can be inserted between mold and product shell is also impacting the heat exchanges. Numerically speaking, the method able at taking all that phenomena into account through an accurate way is a multi-physics 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 slag floating at cast product surface impacting not only the heat exchanges with ambient but also with mold during casting process. An application on continuous casting process taking into account the coupling with the heat control of the mold is presented. Finally, it is shown that the global behavior of the complex system is converging till a quasi steady state, so that it is really possible to optimize the casting process.

Mold flux technologies II / 57

Investigation of mold slag film sampled right below meniscus

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Mold slag plays a very important role in continuous casting process. However, the understanding on the real behavior of the mold slag film in-between the steel shell and Cu mold is still not very

clear in terms of controlling heat transfer and lubrication. The reason is the complexity of the slag film history along the mold and its coupling effect with the temperature and time. In this study, slag film samples were taken from the below meniscus area after casting of a number of steel grades. It is believed that the heat transfer through slag film is the most important factor in this area for casting process. Investigations are carried out in attempt to detail the observations which may provide important information in understanding the film behavior and shed lights in further mold slag development.

Tundish / 58

Open eye formation in a slab caster tundish: Cause and effects

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There are chances of ambient air getting aspirated into the upper nozzle/ladle shroud region that connects ladle to a tundish due to the presence of a negative pressure zone. Inert-gas shrouding is carried out in these regions with the idea to create a protective blanket all around the above-mentioned refractory structures. However, on the downside, some Argon gas bubbles get aspirated into the stream of liquid steel flowing from ladle into the tundish. An upwelling buoyant plume is formed which sweeps off the overlying slag layer and subsequently, gives rise to an exposed region of molten steel, known as the Tundish Open Eye (TOE). Mathematical modeling has been performed to show: (a) the effect of bubble plume on surface velocities of liquid steel and (b) the effect of thin and thick slag layers on TOE size. Finally, results obtained from analyses of inclusions obtained from TOE samples have been presented. The results show that TOEs can be a major source of reoxidation of liquid steel in tundish.

Numerical simulation I / 59

Numerical Simulation of turbulent Steel CEM® mold under high mass flow condition

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POSCO CEM® process can continuously produce coils without cutting before the finishing mill. Material balance with high throughput between the casting and rolling is essential to achieve this process. Throughput of CEM® has boasted a world-class level in the casting area. This was achieved with a high-speed casting technology and increased slab thickness up to 100 mm. Recently, many steel making companies are consistently requiring that higher throughput caster should be manufactured for this kind of directly linked process. To accomplish this high throughput casting, a lot of advanced technologies are required and the stability of meniscus in the mold is one of the important factors. EMBr, Electro Magnetic Braking system has come into the spotlight to control the mold level fluctuation. Therefore, the accurate evaluation of EMBr and some improvement of it, if necessary, are required. In this study, numerical study was carried out for more high throughput condition preparing the next generation of CEM®. The slab thickness is 110mm with slab width 1,600, 1,900mm. In order to effectively stabilize the meniscus, new SEN was designed. Mold flow using new SEN combined with U-shaped EMBr invented by POSCO was numerically evaluated for various external magnetic flux up to 0.35 T. Numerical results are consistently agreed with the plant results currently available by nail board

test. Stabilized mold level is thought to make it possible to accomplish stable casting operation for high throughput case no one has ever carried out in the world.

Numerical simulation II / 61

Utilization of the fuzzy logic regulator and solidification model for improvement the quality of structural S355 steel

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These days the combination and utilization of the advanced numerical simulation techniques with the regulation algorithms is become the common standard in the industry production. In this paper the 3D macro solidification model for continuous casting process and original fuzzy logic regulator is described. The regulator was created in the focus on surface slab quality improvement. The macro solidification model calculates the temperature distribution through the strand and passes the data to the fuzzy regulator. The fuzzy regulator tunes the cooling intensity in the secondary cooling zone based on the temperature field in order to achieve desire temperature profile. This approach is demonstrate on the radial slab casting process for structural steel S355. The real casting data were statistically evaluated from 210 heats and dependency between cooling intensity and final slab quality was statistically proven. The simulation/optimization reacts on dynamic changes in process parameters and give the optimal cooling intensity in the secondary cooling zone through whole casting process which leads to the desire surface quality. The obtained results are also used for quality prediction system.

Tundish / 63

Recent development to improve cleanliness of bearing steel

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An innovative development was carried out to improve fatigue life of bearing steel at West Japan Works Kurashiki, JFE Steel Corporation. First, in order to prevent contamination at the continuous casting, sand filled in the nozzle of ladles is discharged just before starting continuous casting. Secondly, the main composition of tundish flux was modified for better melting performance, such as sealing and inclusion absorbing capacity. With the inventive techniques described above, the fatigue life of bearing steel improved by 3.9 times as many as that of conventional bearing grade.

Surface defects / 64

Hot temperature embrittlement of continuously cast slab of boron containing steel

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An improvement of surface quality of casting slab increases productivity of steel. The slab surface sometimes has transverse cracks along a grain boundary when the slab is bended and/or unbended around the transformation temperature from austenite phase to ferrite one. This defect is mainly caused by film-like ferrite and carbide and/or nitride precipitations around the grain boundary and alloying elements such as Al, B and Nb which have good affinity with carbon or nitrogen also raise the crack sensitivity much more. However, the adverse effect of each element on embrittlement behavior is not necessarily clear. In this study, the effect of boron on the hot ductility of steel has been investigated. It is found that the cooling rate of steel after solidification significantly affects on both the hot ductility of steel and the precipitating morphology of BN. The increase in cooling rate results in precipitating a few hundred nanometer-sized of BN on the grain boundary and worsening the hot ductility of steel. On the other hand, as lowering the cooling rate, BN precipitates on other inclusions such as Al2O3 which distribute anywhere in steel and the hot ductility of steel is improved.

Electromagnetic stirring and breaking / 66

Flow control by FC Mold G3, operation and result from slab casting process.

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The steel quality produced in a modern high productivity continuous caster is greatly increased by a flow modifier controlling the fluid flow in the mold. To achieve a controlled flow in the mold, to stabilize and to improve casting operation, the third generation FC Mold (FC Mold G3) has been mounted in the molds. This electromagnetic equipment combines the conventional double-level DC magnetic fields with an additional AC magnetic field in the upper level to stir around the meniscus. The lower DC magnetic field reduces jet momentum, penetration depth and overall turbulence in the mold. The upper magnetic field creates one homogeneous speed in the front of the initial solid shell and stabilizes meniscus fluctuations. Plant quality results show a surface defect reduction of more than 50% with FC Mold G3 on critical ULC grades made for exposed automotive body panel. A control package is used to master the FC Mold G3 operation. Numerical simulations of the fluid flow, predicting the amount of surface defects, is used together with a “Mold Index”, quantifying the flow intensity in the mold, to allow the control software to adapt magnetic field configurations and strengths to varying caster settings. By proper control of FC Mold G3, in combination with choosing the right SEN parameters, a controlled flow behavior has been achieved for a wide spectrum of casting conditions with improved slab cleanliness and surface quality

Casting of large blooms / 69

Continuous casting machine for oversized blooms

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Summary (200 to 300 words) should be concise and contain all sufficient information for a fair assessment: In recent years, Continuous Casting Machines for big round sections have found worldwide interest and many plants have been installed and commissioned. A significant driving force behind this development is the replacement of ingot casting with a more economic process; at the same time continuous casting, thanks to the homogeneous product it yields, can improve quality of large forged pieces. The same basic requirements lead the development of vertical semi-continuous casters (VERSCON). This process combines elements from continuous- and

ingot casting, and has much higher yield than the latter, together with lower operating costs. VERSCON machines target smaller annual production than continuous casters and are perfectly suited for ingot shops, which strive to improve yield and quality. Due to the different requirements of meltshops worldwide, the design of continuous or semi-continuous machines must be adapted to the intended production and product portfolio (number of strands, casting time, solidification time...) This article illustrates the multiple approaches taken in the design of continuous or semi-continuous casters, referring to the largest bloom caster ever put into service. In 2016, SMS Concast (part of SMS Group) has commissioned a continuous caster for rounds, with product range from 300-mm to 1000-mm round. The design of this caster is explained with reference to the metallurgical processes considered, and is compared with various other concepts developed for VERSCON machines,featuring sections up to 1800-mm round.

Mold level control mold oscillation / 70

New electrical oscillation drive with adjustable stroke and frequency during operation

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Summary (200 to 300 words) should be concise and contain all sufficient information for a fair assessment: An essential part in the continuous casting process is the mould oscillation, crucial for flawless mould lubrication and final surface quality. Oscillation parameters, such as stroke and frequency need to be adapted to the casting speed, steel grades, casting modes etc. The first oscillation movements were made by a simple eccentric shaft driven by an electro motor which allows the online adjustment of the frequency during casting at constant stroke. Therefore, hydraulic cylinders have been used in order to adjust the oscillation parameters frequency, stroke and oscillation shape during operation. On the other hand hydraulic drives are more costly by nature due to the whole hydraulic installation and maintenance needed. This is one of several reasons why the electrical eccentric drives are still used. The new drive concept CONDRIVE (patent pending) developed by SMS Concast AG combines the simple design of the fully electrical eccentric oscillation with the flexibility of a hydraulic cylinder. The stroke is generated by an eccentric shaft but instead of 360° rotation it only partially rotates. The position of the eccentric is accurately driven and controlled by the combination of a servo drive and a torque motor. The sinusoidal oscillation at the mould with a stroke s is generated by a part-turn movement of $\pm\alpha$. The stroke and/or frequency can be adjusted independently by the software at any time during casting by changing the angle $\pm\alpha$ and/or the rotating speed. This feature allows to creating a flexible oscillation drive, reducing capital as well as operational expenses. Furthermore, the new drive can easily be installed in revamps of existing eccentric shaft oscillations. All this makes the CONDRIVE system a potential game changer for the mould oscillation equipment.

Mold monitoring / 71

Accurate mould powder thickness measuring and mould level measuring with one radiometric sensor

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A new advanced radiometric sensor for mould level measurement in closed stream casting has been designed by SMS Concast. The unique feature is to determine both the real position of the steel meniscus and the thickness of the lubricating powder on top. Compared to the

conventional instrumentation this refined setup overcomes the limitation of measuring only a single intermediate level with no possibility to discriminate between contributions of the two materials. The new technology gives access to precious metallurgical information. It also adds the opportunity to tune automatically the powder thickness with no human intervention and leaving the meniscus position undisturbed. This is made possible by an innovative patented design exploiting a vertical stack of multiple scintillator crystals instead of a single one: the crystals are read in parallel to monitor the count profile of the radiation coming from a 60Co rod source. Through a sophisticated algorithm the two distinct levels can be evaluated, being the profile a function of the different material (density) inside the mould tube. Steel level and powder thickness are so determined by means of one instrument only. Laboratory and also plant hot tests have fully confirmed the performance of this new concept. The final engineering design of this new radiometric multi-crystal detector, CONGAUGE LB 6755, has been developed in collaboration with Berthold Technologies, based on their consolidated technological skills. Quick retrofitting into the existing plant configuration is granted on most cases. A calibration tool allows assisted calibration for different casting sections and different flux densities. CONGAUGE LB 6755 will significantly improve surface quality in the continuous casting of steel. This paper explains how initial strand shell formation will become a technologically controlled area.

Mold flux technologies II / 74

Slag rim formation of two mold powders used for casting of construction steel

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At voestapine Stahl Linz two different mold powders are used for casting construction steel, where powder A forms significant larger slag rims than powder B. Their chemical compositions are very similar. The CaO/SiO2 ratio for powder A and B is 1.25 and 1.20 respectively. Additionally powder B contains 0.97 wt% MnO. For the clarification of this difference in performance the melting behavior of the original mold powders was investigated by Hot Stage Microscopy, stepwise annealing and Simultaneous Thermal Analysis (STA). A Furnace Crystallization Test (FCT), the STA and a rotational viscometer were used to characterize the solidification of these mold powders. For the testing of the fluidity an Inclined Plane Test was performed, the viscosity was determined by a rotational viscometer. For the investigation of the microstructure polished sections were prepared from annealed samples as well as from FCT samples. For the slag rims itself cross-sections were investigated by microscopical means. From the investigations follows, that the mold powder suppliers use two different raw material concepts. Consequently the powders do not exhibit identical melting behavior. Contrary to this, as the solidification behavior and the viscosity are dependent on the chemical composition, the deviation of these properties for the two mold powders is only small. Analysis of the slag rims shows a lower part built up by solidified slag and an upper part consisting of partly liquified powder only. For slag rims from powder A the upper part is predominant and displays in contrast to powder B by far more trapping of carbon. Accordingly the difference in the formation of the slag rims is mainly affected by the different melting behavior of the two powders.

Slab casting / 76

E-CO Energy Collector – Energy recovery on the continuous caster at Salzgitter Flachstahl

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The prerequisites for using an Energy Collector (E-CO) for the recuperation of radiant heat are red-hot material at temperatures exceeding 750 degrees Celsius over a long roller table. The slabs are transported to the heat exchangers via the roller table. There, depending on their surface temperature, they radiate between 45 and 70 kW thermal energy per square meter. The heat exchangers take up the radiant energy and transform it into a water-steam mixture. The mixture is separated in the drum and the separated saturated steam is fed to the plant network. Optionally, it is also possible to produce hot water, for example to supply a district heating network. Upon arrival of the next slab, the automatic control system of the roller table signals slab removal, allowing another E-CO procedure to take place. The E-CO Energy Collector was implemented and successfully commissioned at the facilities of Salzgitter Flachstahl GmbH as the first plant of its kind worldwide. The E-CO was integrated at an existing roller table. The cover hoods were modified to suit the recovery process. One special feature of the plant is the reliable control system. Thanks to the sophisticated automation system, a permanently reliable operating condition is achieved. In the case of an indispensable emergency shutdown, no additional switching operation is required.

Internal soundness / 79

HD scan – Ultrasound scans slab quality

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Producers of cast products are in duty to their customers to document the inner quality of the product. The ultrasound measuring is a widely known and well-established technique for non-destructive analysis of the inside of a material used in medicine and many other fields. Every women being pregnant appreciates that very much being able to get the situation of her unborn baby without any big effort to be taken. In the steel industry, ultrasound testing is already used to evaluate the internal quality of as-rolled material. The ultrasound measurement technique of HD scan for the evaluation of internal quality defects in the cast product sample is environmental friendly and needs a less surface processing in comparison to the etching procedure. The clean and safe technology offers three-dimensional views into the sample, providing higher representative information for a better quality evaluation. The quality evaluation is done automatically and based on clear statistical rules. Size and distribution of the segregation are used for a segregation classification. Cracks statistics and narrow side profile contour determination are being realized too. The accuracy of this method is proven by parallel metallographic investigations. Automatic defect determination and classification is compared with macro-etching classification results on more than 100 samples of different cast products. Macrostructure visualization is possible even for samples that do not succeed by macro-etching. Areas of equiaxed and columnar crystallization can be distinguished and quantitatively determined. All this is beneficial for the optimization of cast parameters, such as strand shell cooling, soft reduction or mold and strand stirring. The ultrasound quality evaluation system offers reliable and objective quality results fully independent of etching parameters and subjective quality operator impressions. The hitherto existing etching method may be completely replaced or the number of etching tests will significantly be reduced.

Soft reduction / 80

Future-oriented modernization concepts with proven technology for continuous casting plants

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For many years SMS group modernizes various continuous casters and equips them with state of the art technology. The scope, proven by some 500 revamps worldwide, ranges from small optimizations right up to far-reaching changes of the continuous casters. The concrete measures are defined according to the customer's objectives: the improvement of the slab quality, the expansion of the product range, the enhancement of the process reliability or the environmental protection by energy efficiency.
A comprehensive modernization concept of SMS group includes the mold oscillation and the mold itself. For the mold, SMS group developed the Delta speed narrow face adjustment during casting and the HD mold with breakout prevention system and longitudinal facial crack detection via thermocouples or fiber optics. For extending the strand guide or widening the slab format SMS group has the appropriate solution for production increase or amplified product range in order to make the plant fit for the future. A strand guide system teaming up with the dynamic solidification model DSC® enables Dynamic Soft Reduction®. Applied with the suitable rate at the optimum position it contributes significantly to a homogeneous and crack-free slab microstructure. Perfect alignment of the strand guide is crucial for maintaining an optimum quality. HD LASr aligning assistant with three-dimensional laser measuring system and intuitive operating concept is SMS group's answer. SMS group's air-mist secondary cooling system which is characterized by a fine-adjustable, width-dependent breakdown of the cooling zones ensures crack-free slab surfaces. Thanks to the Eco-Mode allowing on-demand addition of utility systems, the continuous casting plant will meet the increased requirements with regard to environmental protection.

High speed billet casting / 82

Mould developments for high speed casting

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Summary (200 to 300 words) should be concise and contain all sufficient information for a fair assessment: In recent times developments of casting technology for long products are heading increasingly in the direction of high speed casting resulting in significantly increased heat load in the mould. Heat loads exceeding the capabilities of a standard mould tube lead to overheating of the mould; reducing lifetime and performance. The SMS Concast Invex mould technology offers optimized cooling conditions resulting in lower temperatures and reduced thermal stress throughout the copper mould tube. Further developments are pushing the boundaries of knowledge and capability for high speed casting. Using simulation technology it is possible to understand the thermal and mechanical operating characteristics and limits of mould tubes better than ever before. Mould tubes deform under the influence of operational physical loads. Combining optimized cooling and precise calculation of thermal and mechanical deformation allows compensation of detrimental deformation leading to optimised mould geometry even under the most extreme conditions. Further research and practical trials have led to methods of improving heat extraction on the cold face of the mould tube by partial modifications of the surface. Increased turbulence in the water gap results in higher heat transfer and lower temperatures throughout the mould. This technology allows flexibility to improve heat extraction globally or in local zones as required. Finally, the combination of machined grooves on the cold face of the mould tube in conjunction with an integrated water jacket essentially eliminates the negative influence of water pressure while maintaining rigidity and a minimum of copper thickness. These developments allow the manufacturing of innovative mould tubes offering high heat extraction capability without compromise.

Electromagnetic stirring and breaking / 84

Casting of stainless steels and special steel grades

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In 2014 Fuxin Special Steel Co. Ltd., Taiwan, has successfully commissioned a steelworks for manufacturing stainless steel slabs at the Zhangzhou location in the Chinese Fujian Province. The new construction project comprises a special steel plant, a vertical liquid bending continuous slab caster, environmental facilities for gas cleaning and energy recovery and the complete X-Pact® electric and automation. The works is designed for a production of 1 million tons of steel per year. The range of grades produced by the steel plant comprises ferritic, austenitic and martensitic stainless steels, which are processed on the continuous caster to provide slabs in thicknesses of 200 or 220 millimeters. During casting, the width can be set steplessly from 800 to 1,600 millimeters. The continuous caster is equipped with Intelligent Slab Casting modules (ISC®). These include the hydraulically driven resonance oscillator, the HD moldTC (thermocouple) with Breakout Prediction System and Mold Temperature Mapping and the position-controlled CYBERLINK segments. The electromagnetic strand stirrer (EMS) is used for manufacturing very high-quality slabs. EMS enables the formation of fine-grained, globular and homogeneous microstructures and increases the process flexibility and the flow rate. The technologies ensure the internal quality and surface quality of stainless steel slabs. To cool the stainless steel slabs a special logistics for the slab yard was developed. In the presentation we discuss some details of the caster and results regarding production and quality of slabs.

Slab casting / 85

The world thickest (355 mm) austenitic stainless steel slab ever cast - ArcelorMittal Industeel in Belgium

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The challenging task assigned to Danieli in April 2014 involved revamping the single-strand slab caster on a turnkey basis, within a compressed shutdown period of four weeks, including the entire schedule for dismounting, erection and commissioning. Danieli, in close cooperation with the ArcleorMittal Industeel project team, completed all the activities including design, manufacturing, dismantling of old equipment, installation and commissioning of the revamped machine in only 17 months. After an incident free shutdown the caster restarted operation on August 27, and thanks to the skill of the ArcelorMittal operators, supported by the Danieli site team, recorded an impressive learning curve based on a production schedule of 50 sequences through to September 8 when the successful casting of the first 355-mm slab completed a major milestone of the revamping project.
The 355-mm stainless slab cast at ArcelorMittal Industeel in Belgium is a world's first. A project conceived to improve productivity and to open new market segments in the production of heavy plates up to 20 tons each, geared to fabricators of boiler and pressure vessels.
Keywords AM Industeel, thickest slab, Danieli, Revamping, stainless steel, 355 mm

Slab casting / 86

STEC-Roll® - High endurance, easy maintenance

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Strand guide rollers in continuous casters are crucial components for an optimal process for the production of high-quality steel grades. The properties of these rollers greatly influence the

quality of the slab produced. The most commonly used designs so far have been the axle roller and the solid roller. Through an intensive exchange of experience with the caster manager of continuous casters from various suppliers, SMS group has succeeded yet improvement potential in the existing roller concepts. Especially the dismantling and assembly of strand guide rollers play an important role in maintenance. Further it is especially the axle roller and roller with split bearings, whose design obstruct a sufficient internal roller cooling. The STEC-Roll® reduces maintenance costs and enables different types of cooling concepts corresponding to the produced steel grades. A variation of the internal roller cooling allows dry casting of challenging steel grades such as micro-alloyed heavy plate or API grades. With the STEC-Roll® in combination with a suitable cooling concept, all target temperatures can be attained, even in the crack-susceptible edge zone. SMS presents some details about the quick and easy installation and dismantling as well as experience reports.

Tundish / 87

Tundish flow optimization in Aperam Genk for quality improvement

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The decrease of first slabs downgrades and the reduction of clogging on specific alloyed steel grades to increase product quality and extend casting sequence have been one of the priorities of Aperam Genk continuous casting team. High steel quality levels and particularly cleanliness have to be achieved at the beginning of the cast. Tundish filling has been studied along with the influence of the different refractory product geometry on turbulence generation and air entrapment. Ladle shroud position and verticality, Turbostop® design, tundish outlet geometry including stopper nose and casting channel entrance have been evaluated using advanced numerical simulations. These refractory parts have been redesigned to enhance tundish flow performance in regards to NMI floatation, cold steel volume reduction, minimum residence time increase, turbulence reduction during steady operations and during the initial tundish filling

Casting of large blooms / 88

Initial solidification behavior in extra large CC mold at ultra low casting speed

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Demands on high profits and low costs in steelmaking industries are increasing and increasing recently as a result of strong global competition. The continuous casting process has been a good solution until now because of a high yield, energy saving, and omission of blooming process. But there remains to be solved the problem of how to cast an extra large section size strand and high-alloy specialty steel to replace ingot casting process. Therefore a large bloom ingot continuous caster(LICC) was developed by POSCO with ultra low casting speed and more than 120 heat were cast through the LICC pilot caster of 700(T)x700(W)x3000(L)mm bloom. During casting, fluctuation of casting speeds which was 0.05m/min ±0.05mm by LICC occurred due

to oscillation movement. It has been solved by optimum oscillation mode derived from various operating parameters. Initial solidification behavior such as heat transfer, fluid flow and solidifying shell thickness in the mold and surface quality of the strand were investigated for various casting conditions such as casting speeds, mold shapes, oscillation modes, mold EMS conditions, and steel grades. It was found that the initial solidification behavior in LICC strand should be much different from that in a conventional section size strand and surface quality be mainly affected by casting speeds and fluctuation of molten steel level.
Key Words: extra large section size, LICC, ultra low casting speed, LICC pilot caster, initial solidification behavior

Tundish / 89

In or On? About inclusion entrapment in slabs leading to clean steel defects

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Non Metallic Inclusions in the slab may cause clean steel defects such as slivers, blow holes and laminations. The main inclusions found in these defects are mould slag particles, argon bubbles accompanied by alumina or sometimes by slag particles and calcium aluminates. In some occasions clogging products are found. When doing root cause analysis to the origin of these clean steel defects it is difficult to assess where the precursor of the defect got entrapped in the slab. To complicate matters it is found that inclusions already present on the slab surface may be precursors of clean steel defects as well. Knowledge of entrapment location is essential to be able to improve the casting process. This study shows that most – but not all - defects originate from inclusions in the slab and that the entrapment mechanism is related to the type of clean steel defect. It will be discussed how an EMBr is used to improve fluid flow and mould heat transfer thus reducing the risk for defect formation.

Soft reduction / 90

Quality tracking and yield optimization in a continuous caster with mechanical soft reduction

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Summary (200 to 300 words) should be concise and contain all sufficient information for a fair assessment: The market requires that steelmakers of high quality products assure and are able to give proof that their steel is defect free. In a caster, in order to discard portions of defective steel, it is necessary to identify their locations and crop them out. Wasting portions of good steel during this process could cause a serious problem for caster yield. When a significant steel defect is detected by the automation system, two main functions need to be performed. First of all, since a defect may occur in the middle of a cut piece, the planned cuts must be rearranged in order to crop the defective steel out and minimize the waste. Then the position and length of the defective segment must be accurately tracked from its point of origin throughout the caster so that it can be removed at the cutting station. In casters with soft reduction, the latter becomes significantly more complex, because both the cross section and speed of the steel change as an effect of the dynamic reduction.

In this article, we will describe an integrated automation software solution which implements these two features at once: guarantee that the final product is defect free and maximize the amount of good steel produced by the caster.

Thin slab casting / 92

Breakout reduction by prevention of splashes at start of cast in the Tata Steel IJmuiden thin slab caster

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Start of cast breakouts are a major concern for process reliability in the Tata Steel thin slab caster at IJmuiden, The Netherlands. Splashes at start of cast, emerging from the upper ports of the four port SEN, may cause weak spots in the solidifying shell, leading to sticker type breakouts. A threefold approach to investigate splashing behaviour has been followed, linking thermocouple data, visual inspection of front crops and results from water model studies. The combined results suggest that the splashes emerging from the SEN upper ports indeed lead to sticking behaviour at the narrow faces of the mould. Solutions are suggested in order to prevent splashes of steel from reaching the narrow faces.

High speed billet casting / 93

Reliable and radiation-free mould level control system in open steel casting based on smart thermal control system

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The core of CONSAFE is a safe and performant mould level sensor for open stream casting. The patented sensor array includes four thermocouples which are easily integrated into the wall of the copper mould tube. A state-of-the-art controller (ms-cycle) runs the CONSAFE algorithm. It evaluates the dynamic transients of the monitored temperatures and reliably converts the sensor readings into the actual steel level in the mould. The system is embedded into any field bus environment. It would directly drive the withdrawal speed in order to maintain the set-point of the steel level. Each strand controller communicates with the same single monitor station PC. The significant trends and parameters can be configured and checked for all strands on the comfortable HMI interface. One year of production data is stored. The sensor principle allows detecting the presence of rising steel level in the mould before the level reaches the controllable range of the sensor array. This allows to start casting in automatic mode on a regular basis, especially also for small casting section sizes. The most obvious user advantage however is the ability to control the steel level free of radiometric equipment. The extensive range of related OPEX cost (such as special procedures for procurement, handling, disposal of radiometric items or routine health monitoring for operators) can be cut with immediate effect. This paper will explain the CONSAFE product setup and will show impressive operational results from its application in the field.

Slab casting / 94

Hebei Puyang Iron and Steel Co., Ltd. (Puyang Steel), China, successfully commissioned continuous slab caster

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Puyang steel, one of China's leading private steel producers, extended its grade portfolio to very demanding steels with the new caster being designed for a yearly production of 1.2 million tons of not only peritectic micro-alloyed and high-strength steels, but high carbon and boron-alloyed steels, high quality construction steels and pipeline grades. The slab format covers a medium size range of 150 and 180 millimeters in thickness and 1,000 - 2,300 millimeters in width. Furthermore the caster is prepared for a future retrofit to twin-strand casting for supplying a wider market. SMS group supplied the single-strand caster implementing Puyang's wishes and demands in a highly flexible and above all economical way. The new X-Cast® plant and process equipment as well as the X-Pact® electrical and automation systems are tailor-made to fit in the existing buildings. Basing on this the technology packages HD moldTC (mold monitoring), hydraulic mold oscillation and Dynamic Soft Reduction® make it possible to cast the large variety of steel grades and ensure the production of slabs with high surface and internal quality. The straight-forwardness of Hebei Puyang, few interfaces and efficient communication with SMS group resulted in a steep start-up curve leading to a splendidly running production since then. We inform about the project in general and its present status.

Numerical simulation I / 97

Phase-field based solidification model for binary alloy in OpenFOAM

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Variation across different length scales of phase evolution during solidification of steel define the final properties of the cast slab. Various multi-phase models by Ludwig et al 1 and Beckerman 2 for modelling of columnar / equiaxed solidification microstructures in alloys exist in literature. In today's world of high quality steel, understanding the dependence of the solute compositional / thermal profile ahead of the solid-liquid interface on process parameters is of technical importance. Building a micro scale solidification model requires accurate incorporation of the physics of thermodynamics and hence the phase-field method is being used in this work. Authors have found a few publications on phase-field based microstructural evolution in Fe-C alloys containing high percentage of carbon but many cost-effective steels for automotive applications contain low / ultra-low percentage of carbon which is the subject of investigation in this work. OpenFOAM (Open Source Computational Fluid Dynamics Software) based phase-field code for solidification is not readily available and was used for the current work in order to encourage public use in a free and open environment. Starting with a pure metal, an open source micro scale phase-field based model incorporating the thermodynamics of solidification was developed for a low / ultra-low carbon Fe-C alloy. The coupled governing equations were solved using explicit Euler method. Initially the results were validated with what reported in literature for high carbon. Being an open source, to be developed generic code will have the potential for several other applications enabling a wider benefit of the scientific community.
Keywords: Steel, Solidification, phase-field, OpenFOAM
Reference: 1. M. Wu and A. Ludwig, "A Three-Phase Model for Mixed Columnar-Equiaxed Solidification," Metall. Mater. Trans., vol. 37A, pp. 1613–1631, 2006. 2. C. Beckermann, "A Volume-Averaged Two-Phase Model for Transport Phenomena during Solidification," Metall. Trans. B, vol. 22B, no. June, pp. 349–361, 1991.

Bloom casting: New concepts and operational practise / 98

Dynamic soft reduction for round blooms: New concept and experience

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The dynamic soft reduction is more and more applied in bloom casting to improve internal soundness for long products, aiming to achieve consistent and reliable results in reducing V-shape segregation and central porosity. Soft Reduction for Round sections represents a new step ahead in CCM development, requiring a new concept for application to be effective, considering the "shape factor" of round sections. An innovative approach in the design of the modules for Soft Reduction equipped with multiple rolls has been conceived for substantial reduction in the central area of the bloom, being really effective to reduce the segregation. Actual casting tests have been carried out in a revamped strand with new modules and first results in bloom quality shows actual relevant improvements in internal quality. This new concept in Soft Reduction follows the long lasting experience of Danieli CentroMet in this field, casting large and medium bloom sections particularly for High Carbon and Stainless grades in several CCM. Tailor-made solution in powerful equipment driven fully automatically by a mathematical LPC-3Q model allowed further improving in quality for bloom quality. In this paper engineering solutions and quality results of Dynamic Soft Reduction for Round sections are exposed, together with recent quality achievements in stainless and HC grades for bloom rectangular sections. Keywords: Continuous Casting, Carbon Segregation, Porosity, Dynamic Mechanical Soft Reduction, Round sections casting, Rail Steel, Stainless Steel

Slab casting / 99

Modeling complex caster layouts and material flows through discrete event simulation

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The field of computer-assisted layout engineering and material flow planning and evaluation has gained considerable interest in the last years, mainly thanks to the evolution of advanced numerical modeling tools. Danieli has developed a state-of-the-art solution with a dedicated set of simulation libraries able to model the logistics of the entire meltshop, from scrap yard through melting and refining facilities up to ingot or continuous casting and billet storage. In continuous casting, this approach is particularly recommended to replace old-fashioned static machine cycle calculation sheets, making available extensive dynamic information to perform accurate study and optimization of cast product evacuation area. In the example case a continuous caster with a billet discharge system characterized by a high level of complexity is presented, where an extensive feasibility analysis has been performed prior to machine startup and discrete-event simulation has been applied to supply valuable insight into the process and indications for machine and automation optimization.
Key words: Discrete Event Simulation, Logistics, Layout Design, Material Flow, Billet Discharge Optimization

High speed billet casting / 100

Productivity Record @ 75tpy in a single endless line for bars

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Cast-Endless rolling route for deformed bars is establishing as a reliable process for higher and higher productivity at lower operational costs thanks to the energy saving advantages. In IIC-Egyptian Steel Plant it has been started up a new turn-key steel plant designed for the world's highest productivity of 75 t/h in an endless single line. Design capacity has been already exceeded consistently only after three months of startup. The CCM is designed for a combined production of both rebar in endless mode and billets though additional two strands, allowing max flexibility both for rolled bars and as-cast billets, enlarging the annual designed capacity of the plant up to 800,000tpy for both products. Proven technology and reliability of whole plant are the core for stable high casting speed, fundamental for regular endless rolling. The endless process for rebar originally developed in SQ130mm billet section, now it is extended to bigger sections to enhance productivity and sizing the plant capacity to the market specific need. Increased billet section to SQ165mm at casting speed exceeding 6.0 m/min and application of in-line thermo-mechanical treatment on finished products allow a larger margin for energy saving, further lowering OPEX for the plant. In the present paper there are described studies for high speed casting with SQ165 mm billet, the plant startup and relevant steps in achieving the top performances for the endless production.
Key words: Steel, High Speed Casting, Energy Saving, Endless rolling, High Productivity, Induction Heating, OPEX Reduction, In-line Thermo-mechanical Treatment

Submerged entry nozzle / 101

Ultrasonic measurements in a model experiment for continuous casting of round blooms with magnetic stirring in the submerged entry nozzle

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We present an experimental study about the influence of magnetic stirring in the submerged entry nozzle (SEN) for continuous casting of round blooms performed at the mini-LIMMCAST facility at Helmholtz-Zentrum Dresden-Rossendorf (HZDR). The experimental setup consists of a round mould with an inner diameter of 80 mm made of acrylic glass, representing a mould used in industry. A magnetic field, employed by permanent magnets, rotates around the SEN with variable rotation frequencies. In our experiment we use the eutectic alloy GaInSn under isothermal conditions as a model fluid, which is liquid at room temperature. Measurements are carried out using ultrasonic velocity sensors by means of ultrasound Doppler velocimetry (UDV). The sensors are mounted directly at the SEN as well as on several positions along the mould, allowing us to have an insight into the effects by the magnetic stirring in the mould and in the SEN itself. We show a comparison of our results with measurements obtained at the same setup where the magnetic stirring in the SEN is replaced by electromagnetic stirring in the mould by means of a rotating magnetic field (RMF).

Thin slab casting / 104

Longitudinal Facial Crack (LFC) in thin slab casting

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**Quality fist is our slogan in EZZ Steel (EZDK), Egypt, so controlling all casting parameters is very important and interesting topic to deal with. EZDK faced a repeated LFC during production different types of steel grade; many actions were taken to decrease defected coils due to LFC appearance. The actions taken LFC were dived as follows: 1. Process parameters control by casting with constant speed according steel grade and width and also controlling super heat to be within limit values with constant secondary cooling water and so mold cooling water values, controlling taper and heat flux. 2. Steel grade design was done by reviewing all steel grades according to carbon equivalent and ferrite potential to be far away from Peritectic area and decrease possibility of LFC. 3. Mold workshop activates including casting with the same mold 22 heats only and then manual grinding was done in mold workshop to ensure no brass formation in the mold, Dye penetrate test is done after mold grinding, hardness test was done before and after copperplate machining. All above actions decrease LFC \% from 2\% to 0.03\%during 2016 which increase plant quality yield. This topic is considered as practical and perfect good study to increase quality of slab product without any investment and these actions could by applied at any plant around the world.

Operational practises in billet casting / 105

Influence of non-uniform water distribution and water coverage ratio on cooling effect in secondary cooling zone for 82B steel continuous casting billet

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In actual steel continuous casting process, the spraying water in secondary cooling zone always distributes non-uniformly, especially across the width direction of the steel bloom/billet. However, it is generally assumed that the cooling pattern of secondary cooling zone is uniform in many traditional heat transfer models, which will surely result in obvious calculation errors. In this paper, differences of billet surface temperatures for 82B steel continuous casting billet with the cross section of 150mm×150mm are compared between uniform and non-uniform water distribution patterns in secondary cooling zone. On this basis, the water coverage ratio of 82B steel billet is changed to study the temperature variation. Relative results have shown that corner temperature is released and temperature gradient in width direction is lower when non-uniform water distribution pattern is adopted, variation of water coverage ratio results in similar effect in the secondary cooling process.

Slab casting / 107

Dillinger's new continuous caster no. 6

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Dillinger has put into operation a new continuous caster. The fully vertical machine is equipped with 2 strands of a nominal widths of 2200 mm. The thickness varies from 300 to 500 mm in 50 mm increments. Each strand consists of 9 segments allowing the caster to align the slab optimally at any position during the casting process. Soft reduction adjustment of the segments guarantees lowest levels of segregation and microporosity.
The steel solidifies in the vertical part of the caster deploying intensive water cooling. The strands are cut to length with horizontal torch cutters. The resulting mother slabs are tilted into horizontal position and transported to a roller table by crane for bur removal.
The new caster offers the following advantages:

- a maximum slab thickness of 500 mm,
- solidification solely in vertical orientation
- and a fully vertical casting process that no longer requires bending and unbending of the strand.

Internal soundness / 110

MAXILA - A rapid process for analysis of macro-segregation

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Macro-segregation in the center of CC strands can lead to problems during downstream treatment and application of steel. Particularly high carbon or high manganese steel grades are susceptible to form those high concentration areas concerning their pronounced heterogeneous structure during final solidification. Many investigations have carried-out during the past decades to determine those segregations quantitatively. Since the extension of segregated zones is in the scale of 10-3 m and modern CC machines produce nearly dense as-cast structures in the center without big pores like in early days, measuring techniques such as OES, drill-sampling or micro-probe analysis with electron beams are too coarse or too fine to reach sufficient results in a short time. The MAXILA process (Macro-Segregation Identifier by LIBS-Analysis) analyses sample areas, which cover several dendrite arms so that micro-segregation is averaged, and also segregated spots between equiaxed dendrites or V-channels can be identified. This contribution presents the LIBS based semi-automatic analysis system, which has been developed at the Department of Ferrous Metallurgy of RWTH Aachen University. Furthermore, results of high carbon steel strand investigations are presented and discussed. Keywords: Macro-segregation, analysis, as-cast structure, LIBS, MAXILA

New developments in mold flow control / 112

Securing dynamic mold flow control with FC mold and OptiMold monitor

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Electromagnetics is a well-established method to control steel flow patterns in the (slab) casting process. Improvements of process stability, surface and subsurface quality for a variety of casting conditions have been widely reported with the use of mold electromagnetic devices. Building on the success and flexibility of the braking and stirring capabilities of the FC Mold, a supplementary fiber optical temperature measurement system is implemented in one broad face of a slab caster at TATA Steel Europe IJmuiden, aiming to develop the OptiMold monitoring system. Utilizing state of the art Fiber Bragg Grating (FBG) technology, high resolution visualization of the status of the entire slab surface condition is achieved using 2660 temperature measurements distributed over the top half of a broad face mold plate. Using data from more than a year of robust operation, the OptiMold Monitor shows potential to extend accuracy, functionality and performance of conventional thermocouple systems in monitoring local thermal effects. Meniscus shape, flow pattern and speed as well as meniscus asymmetry can additionally be estimated by means of data analysis software. This unlocks potential for dynamic mold flow control where the fiber optical sensor system, undisturbed in electromagnetic fields, is connected in a closed-loop to the FC Mold. Enabling control of steel flow conditions close to the meniscus in a safe, automated solution with direct bearing on steel quality and cleanliness over the entire range of casting conditions in a modern continuous caster.

Surface defects / 114

Influence of MnS secondary precipitation on the hot ductility trough and surface defects of as cast billets

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The hot ductility trough experimental data of as melting samples has been quite well adjusted by the quantity of MnS precipitated in the solid, the MnS secondary precipitation. A numerical model has been developed to calculate the MnS primary precipitation during solidification, secondary precipitation in the solid during the ulterior cooling. The model calculated MnS secondary precipitation has been a useful parameter to explain published data along the years of hot ductility for as melting samples, and some surface defects of as cast billets.

Surface defects / 115

High temperature embrittlement of 2nd and 3rd generation advanced high strength steels

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Within the scope of the collaborative research center SFB 761 “steel ab initio” the castability of high manganese steel grades with varying aluminum and manganese contents via the continuous casting (CC) route is under investigation. Within the current research the high temperature embrittlement of these high manganese steels in the temperature range of 700 °C – Tliq has been examined, using the hot tensile test machine and a new developed high temperature bending simulator (HTBS) at the Department of Ferrous Metallurgy RWTH Aachen University. The HTBS offers the opportunity to induce mechanical stresses on a strand shell with a liquid core in a laboratory scale. In general these high manganese steels show at high temperature a high

susceptibility to cracking. The investigations focus on how the different phases formed during solidification impact the high temperature ductility. To detect the cause of cracking during testing, optical microscopy and scanning electron microscopy (SEM) analysis of the fracture surfaces have been performed and compared to thermodynamic modeling.

Clean Steel / 117

Relationship between oxidic slivers defects on direct rolled Ca treated steel and deposits formed inside the SEN during casting

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We have investigated lamination defects (slivers) on hot rolled coils of Ca-treated steel for microstructure and composition using optical and scanning electron microscopy combined with microanalysis (SEM/EDS). The goal was to identify possible origins for the observed defects which contain a complex assemblage of phases, such as different types of calcium aluminates (CA, CA2, CA6), melilite (C2AS), spinel (MA) and a newly identified defect phase, CNA2. Mould slag similar to that employed during the cast was largely absent from the defects. Analysis of the bulk composition of some of the defects indicated these to be too rich in alumina to be derived from mould slag through steel-slag redox exchange. In contrast, microstructural observation of the inner side of the submerged entry nozzles (SEN) used during casting showed deposits with compositions comparable to those of the defect material. Based on an estimation of the chemical evolution of mould slag interacting with steel, it is found that the defects are not likely to be entrained mould slag but remobilised SEN deposits, as supported by several microstructural and trace phase criteria. We investigated the deposits formed during cast inside the SEN and found that they are similar to the defects in their phase makupp nad composition. However it should be noted that extensive reduction of mould slag by steel can also lead to compositions rich in sodic-calcic aluminates (CNA2), according to exploratory thermodynamic calculations. Therefore differentiation between specific locations of the defect materials within a casting system requires detailed analysis of compositions and microstructures from the potential sources of origin as well as from the materials found in the defects.

Casting of large blooms / 119

A new benchmack in largest round bloom casters

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Danieli sets a new benchmark in continuous casting for largest round sections, after revamping of the CC3 machine in ABS plant (Italy). The startup in Huaigang (PR China) and Baosteel (PR China) as well as new orders of CCM in XiWang and revamping in YongGang confirm the constant market trend in increasing round section sizes for large radius CCM, endorsing the Danieli leadership in this market segment. In case of ABS-CC3 the 18m-radius encloses short pitch among withdrawal modules with six unbending points, enlarging and enhancing the product mix for as-cast production as well as sections in feeding the innovative rotary forge. Casting rounds up to Ø850 mm in diameter on a curved machine is now a reality on large part of the production mix, including ternary grades which are already competing with the quality of the ingot route, ensuring higher productivity and better metallic yield. The top-fed dummy bar, now in full operation in ABS-CC3, guarantees a consistent reduction in restranding time up 60% compared with conventional bottom feeding for the largest section. M-EMS technology, combined with the dynamically controlled F-EMS allows to optimize the quality also in no-steady state conditions, being driven by the new on-line 3D-LPC model for the determination of the

temperature and solidification profile. Danieli CCMs now represent the state-of-the-art of the technology for casting large round section, being equipped with all the up-to-date technological packages for process, automation control and safety. The achieved top quality in round bloom casting demonstrates reliability of the know-how in process knowledge and engineering solutions.

Soft reduction / 120

Installation of dynamic soft reduction system in slab caster to improve hot rolled steel quality

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HADEED commitment to improve steel quality is emphasized by the installation of Dynamic Soft Reduction (DSR) system at slab casters. The system purpose is to improve steel internal quality in terms of reduced internal cracks and centerline segregation, which will lead to higher quality of hot rolled coils. A comparative study conducted to evaluate the influence of dynamic soft reduction system on centerline macro-segregation of API grades. Sulfur-print as a qualitative method was not sufficient to provide clear distinguish of alloying elements concentrations. In addition, Electron Probe Micro Analyzer (EPMA) was utilized as a quantitative method to determine elemental concentration of slab samples. The analysis revealed a decrease in Manganese macro-segregation compared to slabs produced without DSR system. In addition, the study shows the benefits of DSR system in terms of uniform distribution of steel alloying elements by better quality of produced hot rolled API-X60 coils.

Surface defects in slab casting / 122

Improvement of surface quality during continuous casting of type 304 stainless steel

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The black and white band defects of type 304 stainless steel on the hot and cold rolled coils are chronic. The black and white band defects are subsurface defects and can be found chrome carbide in the defects on the surface of the hot rolled coils. The cause of chrome carbide is an increase of carbon near the oscillation mark on the subsurface of slab due to carbuizing of mold powder during the ormation of oscillation mark at the meniscus. The causes of color differences between the black and white defects are as follows : Formation of chrome carbide due to carburizing of slab surface ; Overpickling of chrome carbide layer compared to the normal part in the acid pickling ; Depth differences of defects between the black and white defects ; Color differences visually according to the reflection light. In order to minimize the contact time between the carbon concentrated layer and the initial solidified shell, we change the mold slag properties. This mold powder improves the slab surface quality and also increases the steel yield by reducing slab grinding process.

Internal soundness / 124

Influence of casting parameters in segregation and cracking – Assessment with OES-PDA method

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One of the challenges when casting new high-alloyed steel grades, is to cope with segregation, leading to central segregation. The central segregation is influenced by the cast structure (which in turn depends on the alloy content of the steel melt, on superheat, on secondary cooling) and the machine state.
There are several possibilities to perform an assessment of the macrosegregation (central segregation). Sulphur-prints or other etchants are considered visual methods used to assess the macrostructure of an as-cast slab, without any information regarding chemical analysis. On the other hand, a scanning of the chemical composition by using a microprobe (SEM-EPMA) is highly accurate but time-intensive and costly. By contrast, the Optical Emission Spectrometry with Pulse Discrimination Analysis Mapping (OES-PDA) test is accurate, fast and cheap.
When the results of the OES measurement along the thickness of the slab are related to shell thickness calculations based on 3D modelling of the primary and secondary casting conditions, the effect of different cooling patterns or variations in casting speed can be used to assess the effect of these casting parameters on the segregation.
Moreover, the PDA results can be qualitatively compared to the elements that locally segregate, leading to the formation of unwanted precipitates which in itself, can be related to internal cracking susceptibility. These elements have been detected qualitatively with PDA and through SEM-EDS analysis of the samples, locally some precipitates have been found.
In this publication, a complete assessment of the segregation and inclusions formation with the combination of the above mentioned methods will be presented focussing on two different type of steels, namely the advanced high strength steels (AHSS),and microalloyed grades.

Mold flux technologies II / 125

Novel techniques for controlling heat transfer in the mould-strand gap

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Keywords: mould powder, fluoride free, heat transfer
Abstract: When casting steel grades in the peritectic range it is critical to control the heat transfer from the steel shell in order to minimise longitudinal crack defects. In practice, horizontal heat flux is predominantly controlled by mould flux crystallinity. Cuspidine (3CaO.2SiO2.CaF2) is seen as the most preferable crystal phase due to its high crystallisation temperature and low incubation time. However, the presence of fluoride creates various environmental and operational problems. Research into fluoride free mould powder for peritectic steel grades has so far not yielded a fully effective substitute, as the crystallisation thermodynamics of cuspidine cannot easily be reproduced by other phases.
The current research has investigated whether horizontal heat flux in the mould can be controlled by manipulating the interface between the copper mould plate and the mould flux film. Calculations as part of this research estimate that the interfacial thermal resistance must be increased by 167% in order to successfully cast peritectic steel grades with a fluoride free mould flux that exhibits glassy properties. Laboratory scale measurements have shown that interfacial thermal resistance is increased by the investigated techniques, with one particular technique meeting and exceeding the thermal requirements to cast peritectic steel grades with a glassy mould flux. Further trials were completed on the most promising technique using a “copper finger” test and mould flux film analysis. The results show that the selected technique used in conjunction with a glassy mould flux can produce a heat transfer rate equivalent to that of a peritectic mould powder.

Mold monitoring / 128

A novel view on casting performance: Application of fiber bragg gratings for slab casting

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With the increasing demand on casting process stability, product quality and output, there is a strong need for advanced mould monitoring techniques. Key subjects are meniscus stability, mould fluid flow and mould temperatures. This paper describes the development and application of Fiber Bragg Gratings (FBG) for mould temperature monitoring on a broad face at a slab caster of Tata Steel IJmuiden. The FBG-based system was tested on various steel grades and at casting speeds up to 1.9 m/min. The system proved to be reliable and very useful. In particular, effects of casting process parameters and mould powders were studied. Results were compared to available models. Next steps will include the application of FBG on the narrow faces.

Surface defects in slab casting / 130

Slab section thickness, precipitation and off-corner cracking in microalloyed plate steel.

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Following increasing market demand for thicker plates, work was carried out to increase the cast thickness of a 0.16% C – 1.5% Mn plate grade, microalloyed with Niobium, from 225 mm to 305 mm. This paper describes a surface quality issue encountered during the change and steps taken to investigate the cause. Specifically, fine transverse cracks were observed at around 150 to 300 mm in from the corners of the top face and were not found at any other locations across the width. This location was considered unusual, since most transverse cracking involves some degree of corner cracking.
The cracks were not visible in the as-cast condition, due to them being very fine and masked by heavy oxide scale, but were revealed by scarfing. Metallographic analysis of full transverse pieces cut from skelps that had been scarfed on the top face only, was carried out to determine the mechanism of the cracking and indicated that cracking was occurring after solidification, at a location somewhere below the mould.
Mathematical modelling work to plot the temperature profile for the grade using casting practices for both 225 mm to 305 mm slab thickness provided further clues to the mechanism. Supplementary investigations of the microalloyed precipitation were carried out by SEM using the INCA automated analysis feature. Based on the results of this work, changes to casting practice have been implemented.

Surface defects / 131

New insights into the effect of steel chemistry and caster design on microalloying precipitation and surface quality of low carbon boron steels

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Previous studies have shown that the application of mechanical strain over a long period of time can facilitate precipitation of microalloyed particles. Hence there is a need to clarify whether casting with a multiple straightening scheme rather than a bending/unbending design could be detrimental for the quality of CC of microalloyed steel grades, due to the time extension of the deformation and the corresponding decrease of the strain rate.
Metallographic investigations have been carried out on samples of a Low Carbon Boron grade cast on three different slab casters, having very different bending and unbending strain profiles, at Tata Steel Port Talbot. The work included extensive FEG-SEM analysis using INCA Feature to characterise precipitation and numerical modelling of the industrial casting process to determine temperature profiles of the slabs during continuous casting. In particular the variation in the number of MnS inclusions with distance from the as-cast surface was determined, with unexpected results regarding the location, distribution and particle size. Comparison with data for similar grades produced on the Tata Steel Scunthorpe Slab Caster confirmed conclusions regarding the relative importance of steel chemistry and caster design on the precipitation. Using the FEI Quanta 650 FEG-SEM in combination with an Oxford Instruments Xmax80 detector made it possible to characterise the boron present. The variation in the number and size of BN inclusions with distance from the as-cast surface of slabs was determined. When the precipitate size distribution was examined at each depth, further interesting trends were revealed.
Modified Gleeble tests were carried out on the same Low Carbon Boron grade. The strain and strain rate applied was calculated so as to simulate the strain in the cast strand and cooling and heating conditions of the strand below the mould in the vertical with unbending slab caster number 3 at Tata Steel Port Talbot. The results confirmed the new insights regarding particle size, location and distribution.

Electromagnetic stirring and breaking / 132

Developments in the application of contactless inductive flow tomography

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A major contributor to the quality of continuous cast steel is the flow structure in the mold. In case of slab casting, only the double-roll flow structure is expected to result in optimum quality steel, while other flow structures, like the single-roll or the unstable flow-structure, are generally associated with defects like slag entrainment or non-metallic inclusions. As countermeasures, two kinds of actuators, electromagnetic brakes (EMBr) and electromagnetic stirrers (EMS), are available. It is widely assumed that EMBr can calm an unsteady flow and suppress jet oscillations, whereas EMS ensure better mixing of the melt, even distribution of superheat and avoidance of segregation. Because of the opaqueness and temperature of molten steel, flow measurements inside the mold are hardly possible and often limited to very few points either within the volume or at the surface of the mold 1. Without detailed information about the melt flow, tailored real-time process control is almost impossible.
The contactless inductive flow tomography (CIFT) 2, 3 could help give insight into the transient flow structures in the mold. It operates by applying a magnetic field to the melt and measuring the flow-induced perturbations outside the mold. From those magnetic field measurements the flow inside the mold can be calculated by solving the underlying linear inverse problem.
It was already demonstrated that CIFT can give quite accurate results (compared with UDV measurements) when applied to the flow of GaInSn in a model slab mold, in the case of a two-phase flow 4 or an EMS around the SEN with a downward-directed nozzle outlet 5. Recent publications 6 dealt with a possible application of CIFT in the presence of an EMBr, with promising results. In our paper we will show first flow reconstructions using CIFT when the flow in a model slab mold is influenced by an EMBr and validate those reconstructions with reference UDV measurements.

Additionally we will show preliminary measurement results for a model round billet caster with downward-directed SEN outlet, where an EMS is applied to the SEN.

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Internal soundness / 134

Experimental and numerical modeling of solidification grain structure and segregation in stainless steel continuous casting process

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This papers presents an experimental and numerical analysis of the redistribution of the alloy chemical components, the grain solidification structure and likelihood of porosity formation in continuous casting of stainless steel. An experimental setup consisting of a rectangular ingot was developed to mimic the solidification conditions of a continuous cast slab. The amount of energy extracted from the system was recorded and used as an input for the numerical model. Extensive experimental investigations were carried out to reveal the ingot cross sections grain structure features, including the CET location, and the three chemical component elements distribution. The experimental measurements of the secondary dendrite arms spacing were in agreement with the recorded cooling rate curves. A comprehensive modelling approach was adopted to take into account the effect of the solutal/thermal buoyancy forces driving the overall segregation at the casting scale. The model consists of two full coupled solvers which allow the simulation of grain structure at the full ingot scale. The energy, mass, flow and species balances equations are solved at the macro scale using Finite Volume (FV) method. In addition, the solidification grain structure is computed at the mesoscale; i.e. real time tracking of the growth of solidification grain structure is achieved and coupled with the FV solver resulting in the full ingot grain structure and grains boundaries and features (columnar/equiaxed). The mathematical model was implemented using openfoam, a C++ opensource library, and was validated against experimental and numerical benchmark. The solver, SPrime, was then used to predict the formation of macrosegregation and shrinkage cavity during the ingot solidification. The predicted as-cast structure and the columnar-to-equiaxed transition (CET) were in good agreement with the experimental data. The implantation of a dimensionless Niyama criterion which takes into account the alloy properties; offered better prediction of the porosity distribution.

New developments in secondary cooling / 137

Optimization of cooling in nozzle overlapping area of continuous casting by using experiments and mathematical models

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In the initial secondary cooling zones for the radial slab caster it is necessarily to keep the following conditions: set the hard cooling to remove a large amount of heat when keeping the cooling uniformity to avoid overcooled corners. In these days the problem how to satisfy these requirements is handled by using more cooling nozzles in the one line with water overlapping areas. This paper shows a set of experiments performed for the investigation of cooling behavior in the overlapping areas. The data obtained from the experiments are used as boundary conditions in the 3D solidification model. The numerical model shows that the uniform water distribution or uniform impact pressure does not guarantee uniform surface temperature field. In the beginning of the secondary cooling zone in the case when Leidenfrost temperature is exceeded and temperature locally intensively dropped the surface, then the defects can occur. The results of mathematical modelling and experimental measurements are generalized for an optimal design of the initial secondary cooling zone with more cooling nozzles in one line. The different cooling behavior on large and thin slab cross-section is also demonstrating.

High speed billet casting / 138

CMT „Continuous Minimill Technology“ for efficient production of long products

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Today’s and future steel industry challenges demand sustainability for the production of long products and aims for lowest energy consumption. Further the trend for the installation of small production units utilizing resources from a local area to serve the rolled products in local markets needs a very efficient process directly linking casting and rolling process. Ideally, this process includes a scrap preheating EAF, a high speed casting machine and a directly linked rolling mill. The CMT® (Continuous Minimill Technology) process developed by the SMS group is an inline endless casting and rolling process featuring a high casting speed machine directly feeding the rolling mill. The traditional fossile fuel fired re-heating furnace is eliminated and replaced by a compact on line induction heater for temperature equalization before the rolling process. This paper will highlight various concepts for different range of production, ranging from single to multiple strand concepts, which can be operated via the CMT process. The differences in casting technology between conventional rebar production and CMT casting are explained. As the CMT concepts required high casting speeds special attention must be paid to mould design (SMS Concast INVEX® technology) and strand guidance and secondary cooling. Integrated automation system managing all production process aspects from the scrap yard logistics to the mill finishing area as well as covering maintenance of the plant is also a key element to the efficient and cost effective production of re-bar. The in-line process casting and rolling process requires a integrated level 1 and level 2 concepts. The combination of energy efficient scrap melting together with direct rolling concept drastically reduce the overall energy consumption and consequently the emission of greenhouse gases increasing the environmental sustainability of minimills.

Mold flux technology I / 139

Smart mold flux of dual viscous functions for good lubrication and prevention of slag entrainment in a continuous steel caster mold

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Optimization of CaO-SiO2-CaF2 based flux in a continuous steel caster should be determined from the view point of dual viscous functions for minimizing slab surface defects - high viscosity enough to alleviate flux entrainment at mold top surface where shear rate is about 10 – 40 reciprocal second and low viscosity enough to maximize lubrication capability at oscillated mold wall region where shear rate is around 100 – 1000 reciprocal second. Appropriate liquid mold flux with a strong shear thinning behavior showing significant decreasing tendency of viscosity with increasing shear rates has to be developed for sound slab quality. Flux viscosity was measured by a rotational type viscometer as a function of shear rates. Raman and XPS analysis were employed to understand structural changes of flux for correlating with shear thinning behavior. The present work has focused on developing an optimum mold flux system with strong shear thinning behavior. The strong shear thinning behavior appropriate for dual viscous functions could be achieved by incorporating silicon nitride or silicon carbide into network structure of the liquid flux. The flux compositions with a strong shear thinning behavior will be presented from the viewpoint of clean slab production.

Mold flux technologies II / 140

Study on thermal properties of a low fluorine mold flux

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Fluorine is a crucial component in mould fluxes with a concentration that may reach and in some cases exceed 10% in weight. Fluorine works primarily as a fluxer and chain breaker, its effects include lowering of surface tension, lowering of melting temperature and lowering of viscosity. However serious drawbacks come from use of raw materials containing this element, such as enhanced corrosion activity and toxic gas emission. Studies may be found in literature on partial or total substitution of fluorine with other components with similar properties. This work aims to study thermal behavior of a mold flux for slab casting of crack sensitive steel grades in which fluorine has been partially substituted by other components. In dept characterization of modified low fluorine mould flux by DSC, XRD and laser flash analysis proves very consistent thermal properties of this material compared to standard mould fluxes. Preliminary plant results validate formulative approach and characterization methodology.

Tundish / 141

Ladle purging versus tundish purging during casting for enhanced inclusion removal efficiency

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Non-metallic large inclusions are detrimental to most physical and chemical properties of steel and require a removal treatment. Inclusions can provide crack nucleation sites, surface defects, corrosion sensitivity and will reduce mechanical properties. Gas stirring in the ladle is commonly used in secondary steelmaking to homogenize chemical composition of alloy elements and temperature and to promote inclusion floatation. Ladle bottom gas bubbling is effective in removing none wetted inclusions by two main mechanisms. By the collision and adhesion mechanism, the inclusions will attach to the gas bubbles and rise with them and float up with them with higher velocity than an inclusion alone. Secondly the buoyant plume created by gas bubbles will generate recirculation flow patterns in the ladle, which enhances turbulent mixing to homogenize the chemical composition and temperature, and helps to accumulate and drag and direct the inclusions to the top slag layer and then to be removed. For the inclusion floatation, a relatively low inert gas flowrate is necessary to prevent breaking the ladle slag layer. In JSW Vijayanagar steel plant, in addition to the gas injection during the secondary metallurgy, ladle purging has been also evaluated during the teeming of the vessel. Numerical simulations have been conducted to determine the best location(s) of the purging plug(s) for optimal deoxidation inclusion floatation. The required gas flow rate has been computed in relation to the remaining steel weight. In parallel, gas injection inside the tundish has been assessed and the removal efficiency of de-oxidation + re-oxidation related inclusions has been compared with the ladle and the results presented in this article.

Numerical simulation II / 142

Simulation of continuous casting of steel with EM stirring

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The application of magnetohydrodynamics in the continuous casting of steel enables improved control of the quality of the strand. The most common applications are electromagnetic braking (EMBR) and electromagnetic stirring (EMS). The former slows the flow by applying a static magnetic field and thus improves the steel flow pattern, reduces the velocity and the turbulence of the flow, increases the cleanliness of the material, improves the surface quality and reduces the number of inclusions, whereas the latter stirs the flow by applying an alternating magnetic field and thus improves the quality of the strand, reduces the surface and subsurface defects, enhances the solidification and reduces the number of breakouts. In this contribution EMBR and EMS in a continuous-casting process is considered. The in-house solver employing local radial basis function collocation method (LRBFCM) is used for the solution of coupled mass, energy, turbulent fluid flow, species and electromagnetic field equations. The explicit Euler time-stepping scheme and the collocation with multiquadrics radial basis functions on the five-noded overlapping influence domains are used to obtain the solution of the partial differential equations. A low Reynolds number turbulence model is used to describe the fluid flow, whereas the fractional step method is used to solve the pressure-velocity coupling. The method has been thoroughly tested in several test cases. In the presentation the influence of the application of electromagnetic braking and stiring on the temperature, flow field and macro-segregation in the continuous-casting process for carbon steel is presented.

Numerical simulation II / 143

FEM modeling of thin slab continuous casting strain-stress state

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Coupled thermal and mechanical model of continuous casting of thin slabs produced at OMK CSP was further developed. The model is constructed in the ANSYS Mechanical APDL software. For the tapered funnel mold, thermal 3D and structural 2D task was formulated and solved. For the secondary cooling zone, both thermal and structural problems were set as 2D models. The model is shown to represent sufficiently well important effects intrinsic to the continuous casting process. These are transversal and longitudinal deformation of solidifying shell in the mold, bulging, tension, bending and "soft" reduction under the secondary cooling. Undefined heat transfer parameters describing the mold heat fluxes were determined via solving an inverse problem with some simplifications using thermocouple data of the mold faces. In the secondary cooling zone well known approaches were used to set and check the thermal model. To find the critical points of a cast steel, enthalpy of metallic system, solidification kinetics, volumetric changes, chemical composition of transforming phases as functions of current temperature and initial composition of the steel Thermo-Calc Software is used. This made it possible to evaluate for a first approximation the composition of the phases and their volume fraction (for example, carbonitrides, AlN, MnS) in a solidifying shell relative to the caster important geometric points. The model is also intended to precise the thresholds in the rules of the automatic surface quality system of the casting machine.

Mold flux technology I / 144

A reaction mechanism and model for the composition change of mold flux during continuous casting of high Al steel

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High Al steel containing Al more than a percent has been recently developed which increases specific strength significantly by forming very fine FeAl intermetallic compounds in the matrix. For a successful commercial production, continuous casting is prerequisite, but the high Al content causes serious trouble for the casting practice due to strong reaction between Al and SiO2 in mold flux. In order to find countermeasures against degradation of mold flux properties, it is important to understand the chemical reaction between the steel and molten mold flux. The present paper demonstrates the authors' laboratory scale experimental result showing reaction mechanism between the high Al steel and the CaO-SiO2 based mold flux. Based on those observed mechanism, a slag-metal reaction model was developed in order to interpret the reaction and to predict similar reactions between high Al steel and mold flux used for continuous casting process. The model considers thermodynamic/kinetic information, and the rate-controlling steps observed in the authors' investigation. Thermodynamic information was obtained by ChemApp and FactSage thermodynamic database. This is connected to mass flux equations for all relevant components in the system. Varying viscosity of the flux and its effect on the mass flux are also considered. The reaction model showed good accordance with of the experimental data. Some possible applications are also shown.

Clean steel and clogging / 145

Interfacial reaction between ultra low C steel and refractory material used for submerged entry nozzle for continuous casting

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Ultra low C (ULC) steel is one of major products of high quality steel in a number of steelmakers. Slab of the ULC steel is produced by continuous casting process in order to maximize process efficiency. Ti is one of important alloying elements of the ULC steel, in order to secure good formability of the steel, as it is used for outer panels of automobile. It has been a long problem that increasing Ti content in the steel increases extent of nozzle clogging during the continuous casting process. In the present study, the clogging phenomena for the Ti-ULC steel is reviewed, and possible source of the formation of clogging material is discussed. Particular attention has been paid to the interfacial reaction between the Ti-ULC steel and the refractory material use for submerged entry nozzle. Phase diagram of the steel-refractory system is applied in order to figure out what types of materials are formed, and how this Ti affect the formation of such material at the interface between the steel and the refractory.

Clean Steel / 146

Investigation on interfacial tension between the slag and initial solidification shell affecting sliver defects

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The mold flux is the most important thing for the lubrication between the mold and initial solidification shell in continuous casting process. However, in the process, the mold slag generated by the mold flux is entrained into molten steel and brings about the surface defects of IF steel. Generally, in order to reduce the entrainment of the mold slag, continuous casting plants have tried to change the characteristics of the mold by reducing casting speed, optimizing molten steel flow control. In the present study, the defect mechanism in the mold is reviewed and the defect reduction technologies in the solidification process are discussed. In reducing the mold flux defect, interfacial tension between the slag and molten steel is important. As a result of laboratory experiments, the interfacial tension of the mold slag has changed according to the composition of the mold flux. Alkali-oxide has played a key role in increasing the interfacial tension of the mold slag. The result has been applied to a continuous casting plant and the number of the slag defects has reduced sharply.

Thin slab casting / 147

Refractory design and process optimization in Tata CSP® caster

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Technical solutions and design optimization for better quality, increased productivity and yield have been continuously introduced and implemented in Tata Steel thin slab plant located in Jamshedpur – India to further improve competitive edge in the current steel market. Extensive advanced computer simulations and physical simulations have been conducted to determine the different parameters characterizing both tundish and mold flow. Reduction of dead and cold steel volume, improved inclusion floatation and turbulence reduction in the impact region have been obtained after optimizing the internal tundish geometry. With the new tundish internal geometry, the tundish skull weight has been reduced by 20% with out any quality issues. Addition of tundish gas bubbling device aka TGD is introduced, installed & under evaluation to achieve

the reduction of process issues. The new Sub-Entry Nozzle is used to produce stable meniscus flow and optimal mold temperature distribution for flow rate at around 11% higher Thpt than current design & it is planned to increase thpt by further 15% by further study..
Keywords: Thin Slab SEN, CSP®, YES tundish, tundish skull, TGD, SEN design

Plenary Session / 148

State of the art technology in slab continuous casting: A casting speed point of view in POSCO

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Over the last 50 years, continuous slab casting processes have been widely installed over the world taking advantage of their enhanced productivity, yield, energy consumption and labor efficiency. Nowadays, the continuous slab casting can be divided into four categories as casting thickness: strip casting, thin slab casting, thick slab casting and ultra-thick slab casting processes.
Strip casting processes which directly produce thin strips (less than 5mm) from molten steel are being improved to cover more steel grades with 30-100 m/min casting speed. Thin slab casting processes with slab thickness less than 100 mm begins to be connected with a subsequent endless-rolling process in order to easily produce the ultra-thin gauge products by increasing the casting speed to 5-8 m/min. For the conventional thick slab casting with 200-300 mm slab thickness, higher casting speed is interested in a view point of the balance of converter, caster and hot rolling mill capacity. In order to guarantee the slab quality of heavy gauge plate as the energy and shipbuilding materials, ultra-thick slab casters with 400-700 mm slab thickness are designed. In this case, the casting speed is seriously limited less than 0.4m/min because of metallurgincal length limit.
In the case of thick slab casting at a low casting speed, the control of meniscus freezing, centerline segregation and bending/unbending within caster are the key technologies. For thin slab casting at a high casting speed, the control of mold level hunting, molten flow in the mold, high frequency mold oscillation and surface quality are important problems. In this article, the inevitable reason why the range of casting speed has been spread out is discussed. The above continuous casting processes are briefly introduced and the related key technologies based on POSCO's experience are reviewed in the view point of casting speed depending on slab thickness.

New developments in mold flow control / 150

The effect of the position of a submerged entry nozzle (SEN) exit ports on fluid flows, and meniscus stability, for square billet casting molds

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A computational fluid flow model has been developed to simulate the flow field of liquid steel within the square mold region of a billet caster. This study reports on the dramatic effect that a Submerged Entry Nozzle's (SEN) position can have on fluid flows developed in square, curved mold, billet casters. In this study, ANSYS Fluent 14.5 software was used to model the 3-D turbulent flow of liquid steel in the mold region, and the Realizable k-ε model was used to simulate turbulence. Similarly, the Volume of Fluid (VOF) multiphase model was used to simulate the effect of fluid flow on the liquefied mold powder at the liquid steel's upper meniscus. Predicted behavior of flows within the mold region was validated against previous experimental work. Predicted results showed that changing the SEN angle of rotation with respect to the

corners of the square billet mold, plus the slight mold curvature, can significantly influence the flow patterns generated within the mold region and the stability of the upper meniscus, and thereby affect the finished quality of the square billet products.

Bloom casting: New concepts and operational practise / 151

Pre-evaluation of as-cast round bloom quality from monitoring of process records and temperature measurements

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In the objective to improve the internal soundness of the as-cast round format 400mm in ArcelorMittal Ostrava, a strong collaboration has been launched between the team of the steel plant and the R&D centre of Gandrange, specialized in long products. In this framework, a focus has been made on forging grades, which have shown a high sensitivity to the occurrence of central cracks and porosities. In particular, these grades have presented strong variations of in terms of quality characterization by ultrasonic testing. Thus, a long-term acquisition campaign has been carried out on the caster, including records of casting parameters, measurements of product temperature and tracking of quality results. After combination of casting simulations and statistical data analyses, it has been possible to correlate the occurrence of defects to the conditions of cooling and solidification, and to define a set of safe casting conditions. This set has now to be enriched with more production records and quality results, in order to achieve an industrial tool for pre-qualification of as-cast products.

Slab casting / 152

Weld-overlay – How to make the best choice to extend the service life of your continuous casting rolls

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When continuous casting rolls are in operation, the load pressure and temperature changes from the top segment at the point of continuous contact to the horizontal zone. During this process, rolls must withstand the following phenomena: [U+F0A7] Elevated temperature [U+F0A7] Intensive water spray cooling [U+F0A7] High slab contact pressure [U+F0A7] Fatigue due to cyclic thermal and mechanical stresses [U+F0A7] Adhesive and abrasive wear [U+F0A7] Corrosive environments Roll surfaces deteriorate under these service conditions, so weld-overlaying is the best option to extend their service life. This weld procedure can be applied as a preventive or as a remedial measure.
This article gives an explanation as to why martensitic stainless steels (SS) are commonly used to weld-overlay rolls. It will also be shown that different overlay chemical compositions can be used according to the roller location, i.e. depending on the segment of the continuous casting machine. The influence of each chemical element in overlay performance will also be reviewed. The article concludes with a detailed review of the welding processes and the final heat treatment.

Clean steel and clogging / 155

Investigation of the causes of ladle nozzle clogging during steel pouring

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Nozzle clogging during steel pouring in the continuous casting process is a long-standing problem for Al-killed steels. During casting the flow rate of liquid steel through the nozzle is reduced due to the nozzle clogging, which leads to serious operational problems. Even though the ladle slide gate is fully open, the molten steel flow rate can hardly meet the demand of the tundish, causing the level in the tundish to drop. To continue the casting sequence the casting speed must be reduced. In some cases casting is terminated if clogging takes place at early stage of ladle opening and the ladle returns with the remaining steel poured in the EAF for reprocessing. Ladle nozzle clogging reduces productivity and impacts the steel quality. This paper investigates the causes of ladle nozzle clogging and proposes counter measures to it.

Operational practises in billet casting / 156

The Influence of Casting Speed, Mould Powder and Oscillation Parameters on Mould Level Fluctuation

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In order to decrease the mould level fluctuation the casting parameters such as casting speed, mould powder and oscillation type have to be optimized. The general full factorial design of experiments were successfully carried out two times. In these experiments two different mould powder and sinusoidal/non-sinusoidal oscillation types from high to low casting speeds were investigated in-situ continuous casting. Although the basicity of mould powders is same; the additives of mould powders are different from each other. The standard deviations of mould level fluctuation were investigated by using ANOVA. The mould powder and casting speed are resulted to be statistically important variables; on the other hand, the oscillation type is considered as inefficient. The error of ANOVA showed that there is a significant variable that has an influence on mould level fluctuation. According to literature reviews this significant variable can be bulging in upper secondary cooling zone. The optimum conditions to achieve the lowest mould level fluctuation is mould powder with Na2O, sinusoidal type at casting speed 1,20 meter/minute.

New developments in secondary cooling / 157

Secondary cooling with pulsed sprays: Enhanced cooling range and lower operating costs

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In continuous casting secondary cooling the cooling intensity has to be accurately adjusted in order to achieve the desired strand surface temperature. The cooling intensity can be varied by changing the water flow rate through the nozzle. For a homogeneous cooling effect the nozzle flow rate must not drop beyond a nozzle-specific minimum value. In many cases lower cooling rates are required, which can be realized by a pulsed spray water supply. Heat transfer simulations of the strand shell temperatures during pulsed spray cooling in comparison to continuous spray cooling show that the pulsed spray cooling can effectively extend the nozzle's cooling intensity range towards lower values without any drawbacks. A further benefit is the reduced air consumption in comparison to air mist nozzles.

Mold monitoring / 160

A new instrumented mold powder diffuser with built-in optical sensor for powder thickness control

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The key impact of mold powders on steel quality is well-recognized. However, manual feeding is still a widespread practice, leading to powder thickness variations, meniscus instability and poor process reproducibility, with negative effects on steel quality. Dedicated technologies for automated powder feeding are therefore crucial. A new mold powder diffuser with built-in optical sensor for powder thickness control has been developed and successfully field-tested. Being based on laser-line technology and dedicated triangulation algorithms, the sensor provides a robust measurement of powder level, while being non-invasively integrated within the diffuser of an automated powder feeder, enabling reliable closed loop powder control.

Electromagnetic stirring and breaking / 163

VUHZ electromagnetic mold level measuring system on thin slab caster equipped with electromagnetic mold brake

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The paper shows the long time trial of edge type of the electromagnetic VUHZ Mold Level Measuring System (MLM System) on Thin Slab Caster equipped with Electro Magnetic Brake (EMBR). Trial was realized in Rizhao China on Primetals ESP (Endless Steel Plant). Three MLM systems (X-ray, electromagnetic edge and suspended types) simultaneously were used for measurement of the steel level in the mold at the same time. Obtained results and trends confirmed the suitable usage of edge type of electromagnetic MLM system on Thin Slab Casters from the point of the wide detection range, good similarity with other MLM systems, stopper regulation, short and long time fluctuation, no interference from EMBR and last but not least sensor installation in limited space on the mold upper part. Some of benefits of edge type of electromagnetic MLM systems seem to be important especially on ESP: - Ready to cast: fast installation of sensors on the mold, one point checking of function, no necessity of calibration, permanently installed on the mold to measure steel level during the whole casting sequence - Steel level detection method: measuring of the true steel level without slag and casting powder - Fast measuring signal proceeding in the digital evaluation unit suitable for high speed casting, low noise, high signal stability - Easy maintenance, long life time of MLM system, repairable sensors, overflow riding out - Harmless

Submerged entry nozzle / 164

Simulations to design thin slab casting SEN and the SEN's applications at work

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To improve the productivity of continuous casting, the adoption of thin slab caster is being steadily increased. Due to high speed casting of thin slab caster, the optimized deign for SEN becomes precondition for stable operation in casting. Design technology for SEN has been improved through fluid flow analysis and thermal stress analysis by computer simulation and water model experiment. Depending on presence of EMBR(Electro Magnetic Brake Ruler), There are two different ways of SEN design concept. In this paper presents the simulation process for SEN design and application result at works for each case. In case with EMBR, we designed large SEN to be able to cast over 6ton/min. The bore area of SEN is designed sufficiently large to induce stable steel flow in the surface of mold in casting. By numerical experiment and water model experiment, stable flow is verified. Also, through FEM analysis, the thermal shock risk due to enlargement of SEN is minimized. In the real application, at 8m/min casting speed, the optimized SEN performed successfully showing stable surface flow in mold and after that there has been no trouble by thermal shock up to the present. And the case without EMBR, The steel stream inside of mold is decided by the design of SEN and it influence to slab quality directly. The dimension of discharge port and inner bridge is optimized by computer simulation to inclusions flotation and uniform temperature distribution in mold. And the computer simulation results are verified by water model experiment. And the SEN has good performance at works.

Numerical simulation I / 165

Water modeling on the multiphase fluid flow in a continuous casting mold

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In the current work, an one-quarter scale water model was established to investigate the effect of bubbles and slags on the fluid flow in a slab continuous casting mold. The variation of the profile of the top surface and the critical condition for the entrainment of slags were studied using a high-speed camera. A Particle Image Velocimetry (PIV) was used to measure the fluid flow velocity and turbulent characteristics, considering the effect of slag phase and bubble phase. It was found that the slag phase could press the surface velocity and level fluctuation. The maximum casting speed and minimum submergence depth of SEN to prevent the entrainment of slags were also investigated.

Clean Steel / 166

Oscillation marks and subsurface hooks in continuous casting slabs of ultra-low-carbon steel

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Oscillation marks (OMs) can be classified into depression OMs and hook-like OMs, near which subsurface hook structures appear in ultra-low-carbon steel of continuous casting slabs. In the current study, the hooks of whole-leaf type, truncated type, re-solidified type and double-hook type were observed, and bubbles were found below hooks, indicating that hooks could capture the floating bubbles. Inclusions from the slab subsurface near hooks were detected using automatic scanning electron microscope (ASPEX), and some inclusions were gathered near hooks which could be detrimental to the surface quality of continuous casting slabs. And more inclusions at large size were tend to gather near the hook line, indicating that large inclusions were apt to be captured by hooks. In order to minish the influence from the subsurface hooks, experiment of reducing water flow rate in the mold was conducted to decrease the hook depth. And the

analyzed results demonstrated that the mean hook depth became smaller after reducing the water flow rate from 5940 L/min to 5300 L/min in wide face. Accordingly, appropriately reducing the water flow rate in the mold can minish the hook depth and the damage from the hooks.

New developments in secondary cooling / 168

Development of mist spray nozzle of saving energy type in a continuous casting process

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Secondary cooling is an important process in continuous casting in the steelmaking division from the viewpoints of stable industrial operation and the quality of cast slabs. Historically, hydraulic spray nozzles were originally used in the continuous casting process, but mist spray nozzles were developed subsequently to prevent clogging of the nozzle tip and surface cracks of cast slabs. Moreover, higher slab cooling capacities have been needed to cope with high speed casting operation over the wide range of water spray rates in the secondary cooling process. However, there are few reports on the cooling capacity of the secondary cooling process, especially the spray thickness and the collision pressure in the casting direction. In this study, laboratory experiments on the cooling capacities of hydraulic and mist spray nozzles were carried under various conditions by developing several kinds of hydraulic and mist spray nozzles. From the experimental results, in order to achieve a high cooling capacity in a spray nozzle, it is important to select the proper spray thickness and collision pressure when designing the nozzle.

Casting of large blooms / 169

Segment casting – A semi-continuous casting technology for high-end semi-finished steel products

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Segment Casting (SC) is a novel casting technology which combines the technologies and benefits of continuous casting and ingot casting, without limitations to steel grades to be produced. The bloom is vertically cast to a defined length and subsequently treated in-situ with various technologies until final solidification is completed. The key technologies are the combination of

- A sophisticated dynamic electro-magnetic stirring strategy acting as mould/sub-mould/final and hot top stirrer for improved quality and yield
- An inductive feeder acting as liquid steel reservoir to compensate solidification shrinkage, improve centre soundness and improve yield

The paper outlines the casting technology and OPEX advantages of this novel casting technology

Mold level control mold oscillation / 170

Developments for a hydraulic free casting platform for continuous casting to improve operational and production safety

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In order to improve operational safety and at the same time process stability and product quality, new technologies have been developed and implemented in Continuous Casting to eliminate the use of hydraulics in the casting platform area. This paper outlines the developments and technical solutions in continuous casting for hydraulic-free casting platform operation for e.g.:
• Accurate mould level control (Mould Level Master) by stopper rod mechanism • Pneumatic emergency slide gate actuation • New electro-mechanical servo-drive oscillation with dynamic adjustments of frequency and stroke
Operational Advantages will be outlined.

Mold flux technologies II / 171

Effect of CaO/Al2O3 ratio on steel-slag interaction for high-Al steel casting

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High-Al steels attract wide attention in the automobile industry owing to their excellent combination of high strength and superior formability. The reaction between Al in the liquid steel and SiO2 in lime-silica-based mould fluxes during the continuous casting of these steels causes chemical compositional changes in the mould flux, subsequently affecting the surface quality of slabs. In order to solve the aforementioned problem, lime-alumina-based mould powders have been developed which can lead to an increase in the surface quality of cast slabs by inhibiting molten steel/mould powder interaction. However, the mould slag tends to crystallize easily, which results in mould lubrication deterioration. Therefore, knowledge of liquid steel-slag interaction is required to select the appropriate casting powder. Changes in physical properties such as crystallinity and melting behaviour of lime-alumina-based mould powders with increasing CaO/Al2O3 ratio have been observed through STA (Simultaneous Thermal Analysis), HSM (Hot Stage Microscopy) and XRD (X-ray Diffraction, and changes in slag chemistry over time have been analysed using XRF. This paper will present a summary of these results.

Clean Steel / 172

Grain refinement of solidification structure by direct inoculation

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As grain refinement can bring the substantial improvement of mechanical properties of as-cast and further rolled materials by reduction of segregation during solidification. Many studies, therefore, have been reported on grain refinement of as-cast structure by formation of inclusions based on so-called Oxide Metallurgy. However, there are also many problems in Oxide Metallurgy in terms of process controlling: Steel making process should be overloaded by increase of overheat in steel melt, the applicable steel grades are limited, and there exists a high possibility of nozzle clogging. In order to overcome these limitations, in this work, inoculant alloys were directly injected in molten steel in lab scale. It should be emphasized that any kinds of diverse inclusions could

be utilized as the candidate of inoculants by direct inoculation method. Inoculant alloys were prepared by mechanically alloying steel powders with inoculants which have lower disregistry (lattice misfit parameter) with each other, followed by heat treatment and rolling in order to remove moisture and holes inside. The experiment was carried out by using 1kg-scale solidification simulator. Then, solidified as-cast steels were analyzed by using various kinds of analyzing devices in order to verify the grain refinement effect. It was observed by SEM-EDS that various kinds of inclusions were made. Also, the effectiveness of refiners was confirmed by EBSD and OM.

Mold flux technology I / 176

Slag entrapment behavior of molten mold flux technology

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A Molten mold flux technology so called, POCAST process has been newly used to enhance the slab quality of Ultra Low Carbn Steel(0.001˜0.002 C%). Due to the thicker slag layer and higher temperature of meniscus, POCAST technology can influence in many ways; shorten the hook length, decreased C-pickup on the slab surface, less inclusion within the slab, enhancing the slab lubrication and etc.. In this papaer, measures on slag entrapment behavior is introduced varies with molten slag layer using water model compared with commercial practice results.

Surface defects / 177

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 peitectic 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.

New developments / 178

Experiences of pilot slab caster for development of advanced casting technologies

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Since pilot slab caster was operted in 2003 at POSCO, many casting tests were performed in this caster. Because this facility with a heat size of 23 tons is nearly half scale of the actual caster, advanced casting technologies have beed developed and applied in commercial caster.
One of these technologies is high-speed casting. Design concepts of segment and cooling sytem, operation conditions in high-speed caster are realized in the pilot caster. Maximum casting speed of our conventional and thin slab caster reached at 2.7 m/min and 8.0 m/min, respectively.
Heavy reduction process for minimizing center segregation and shrinkage cavity significantly is new technology developed by POSCO. The specially designed segment and in-roll EMS (Electro Magnetic Stirrer), the core facilities of heavy reduction process, were tested at the pilot caster and implemented at 3-1 slab caster to produce heavy plates at Kwangyang steel works.
Recently, casting technology for high maganese steel grade have been developed at pilot slab caster.
In this presentation, it will be reviewed the experiences obtained during 14 years operations at pilot slab caster. The advanced casting technologies will also be discussed based on the results at both pilot slab caster and commercial caster.

Bloom casting: New concepts and operational practise / 179

New 5-strand bloom continuous casting machine with soft reduction for high-end tire-cord production

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In 2016 a new 5-strand bloom caster was installed and successfully commissioned by Inteco melting and casting technologies GmbH at Jiangsu Shagang, Shagang Group (CN). The CCM is designed to cast section size 300 x 390mm on a 9m vertical bending-unbending machine equipped with latest SBQ-Technology. Besides other features, a tundish design with optimised liquid steel flow distribution, large corner radius mould tube design, powerful M-EMS combined with 9 Modules for dynamic Mechanical Soft Reduction place the CCM at a unique level to produce blooms at high productivities with flawless surface quality and excellent internal quality (large equi-axed zone, low inclusion level and low segregation level), esp. required for tire-cord grades. First metallurgical results of the new CCM will be presented

Tundish / 181

Tundish furniture optimization to maximize steel quality

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The flow pattern in the tundish is critical for final product quality, as it influences the cleanliness of the steel entering the mold. Poor tundish practice can lead to surface level fluctuations, eroded refractory particles and cold regions, leading to defects in the cast product. On the other hand, by achieving an optimal flow pattern, it is possible to not only prevent inclusion formation but even promote their capture, leading to a cleaner steel. A desirable flow pattern also improves the control of steel composition and temperature. This paper presents fluid dynamic numerical simulations of different tundish furniture designs. The flow control devices position and size were optimized through a computational technique with the goal of maximizing the melt's residence time in the vessel. By these simulations, it was possible to design effective tundish furniture to provide cleaner steel for the mold.

Surface defects and postprocessing of slabs / 182

Highly flexible deburring grinding machine for a reliable burr removal at front, tail and side edges of continuously cast slabs, blooms or billets

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Depending on the product or the material grade, conventional deburring machines, such as e. g. with rotating hammers are in many cases not capable to reliably or completely remove the burr from the edges and corners of a continuously cast product. Burr, however, is generated at the front and/or tail ends of a slab, bloom or billet as a result of torch cutting. Likewise, traverse grinding of the slab's rolling surfaces can also cause burr at the long side edges of the slab, whereby such burr can even be more difficult to remove. Based on their experience and know how with abrasive machining processes (abrasive cutting, high-pressure grinding) over a period of more than 50 years up to now, BRAUN has developed a highly flexible deburring grinding machine for applications which are too difficult for conventional deburring techniques. BRAUN's deburring grinding machines were successfully introduced to the steel and special metals industries and have proven their worth under normal production conditions already. The subject paper describes the key features and advantages of BRAUN's machine design and the operational results from the first already completed Projects.

Surface defects / 184

The influence of compositions on hot ductility of high Al TWIP steels

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TWIP (Twining Induced Plasticity) steel is very promising AHSS (Advanced High Strength Steel) grade owing to its superior toughness and ductility. Recently it has attracted the interest of the automotive and steelmaking industries, as the need for reducing weight to provide better fuel efficiency is of paramount importance with the gradual depletion of fuel resources. But these steels are difficult to continuous cast and cracking can occur at the slab surface. Therefore it becomes very important to gain an understanding of the cause of this cracking, in order to prevent their occurrence. In order to gain a better understanding of the cracking propensity in high Al TWIP steel slabs(1~1.5%Al), conventional hot tensile tests were performed to simulate the

continuous casting process on a variety of TWIP steels in order to determine the influence of such factors as chemical composition, cooling rate and thermal cycle on hot ductility. Using a cooling rate of 60K/min after heating to 1250oC, ductility was generally <40% RA(Reduction of Area) indicating that with these high Al TWIP steels it will be difficult to avoid transverse cracking. The 1.5%Al containing steels had worse ductility than the low Al containing steels(0.02%Al) because of the presence of large amounts of AlN precipitated at the austenite grain boundaries. Higher strength Nb/V high Al containing TWIP steels were also examined although ductility was likely to be worse than the simpler microalloying free TWIP steels. Increasing the cooling rate from 60 to 180K/min after melting caused the ductility to further deteriorate and high N levels produced only a small reduction in the ductility, probably because ductility is so poor. Increasing the S level from 0.003 to 0.023% caused the ductility to deteriorate in TWIP steels free of microalloy. The worse ductility in the higher S steels was found to be not caused by a simple increase in the sulphide volume fraction but more a consequence of the change from coarse hexagonal plate AlN, which are mainly within the matrix and so have little influence on the hot ductility, to very long dendritic rod precipitates, which are situated at the dendritic or close to the austenite grain boundaries. This dendritic precipitation was rarely observed in the low S steel. The MnS inclusions appeared to act as nucleation sites for the precipitation of AlN. The influence of P in the range ˜0.01 to 0.07% with high Ti and N additions on the hot ductility of 1.5%Al, boron treated TWIP steels has been examined. P even at the 0.02% level has a small detrimental influence on the hot ductility and ductility decreases progressively as the P content is increased. Low melting point Fe(Mn) phosphide phases were found at the austenite grain boundaries accounting for this deterioration in ductility. As it is difficult to cast these steels, without cracks forming, P levels should be as low as possible, preferably ˜0.01%. The ductility of Nb containing high Al, TWIP steels was very poor in the as-cast condition. Adding B and Ti still gave rise to extremely poor ductility when a cooling rate of 60K/min was used but reducing it to 12K/min caused the ductility to improve so that RA values were now close to the 35˜40% RA value required to avoid transverse cracking. Both 0.04%Ti and 0.002%B are required to ensure good hot ductility in high Al,TWIP steels. Sufficient Ti is needed to remove all the N as TiN so preventing AlN precipitating as films over the austenite grain surfaces. B is also needed as it can segregate to the boundaries and strengthen them. A SIMS technique confirmed that B had indeed segregated to the boundaries. The slower cooling rate 10˜15K/min compared to 60K/min will result in the optimum segregation of B as well as coarsening the TiN precipitates so they are no longer effective in reducing the ductility. Following all these recommendations, i.e. a low S level, slow secondary cooling rate, a Ti level above the stoichiometric for TiN and a boron addition of 0.002%, transverse cracking was avoided commercially in these very difficult to cast high strength TWIP steels

Numerical simulation II / 185

Numerical simulation on soft reduction parameters design to aviod internal cracks in slab casting

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Fully coupled thermo-mechanical finite element models were developed, also casting and soft reduction tests were carried out in an industry casting machine, to investigate the formation mechanism of one kind of typical inter-dendritic crack around triangular zone in slab casting process, applying soft reduction technology. The effect of soft reduction amount distribution design combined with total soft reduction amount, upon aimed the soft reduction region, on the internal strain status were analysed. The relationship between the typical inter-dendritic crack and soft reduction condition was presented, which has been proved by the production practice. Considering the critical strain of internal crack formation, a critical tolerance for the soft reduction amount distribution and related casing parameters have been proposed for better contribution of soft reduction to the internal quality of slabs. The occurrence of the typical inter-dendritic crack around the triangular zone has been eliminated effectively through the application of proposed suggestions for continuous casting of pipeline steel in industrial practice.

Surface defects and postprocessing of slabs / 186

Real time monitoring of hot steel slabs during casting and automatic slab surface quality assessment enabling fast utilization of quality information feedback – for planning of grinding, fast evaluation of trials and online feedback of maintenance needs.

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By the visual inspection of the hot slabs during casting it is possible to observe only major defects and only on the upper surface. So the inspection of cold slabs later is needed, especially if trials were made. And in practice inspection of all slabs is nearly impossible. So there was need for a tool to have images from the hot slabs during casting – for several purposes. A tool called Reveal CAST was developed. With this tool it is possible to take images from the hot slabs after cutting. With the special technique used to avoid thermal radiation surfaces of the slabs looks like taken from cold slabs. Images are taken from the all slabs and if needed from the all surfaces. Automatic defect detection is included. In this paper is presented several examples of the images and how they can be used to define the surface quality of the slabs. Also including cases how the images can give the respond on the surfaces of the slabs concerning when it is found abnormal events with online measurements like thermocouples. It is shown cases how slab surface can change gradually during casting from start to end and how this change can be connected to the heat transfer in the mould. For this kind of study it is needed to have 100 % coverage of the images of the all slabs. Images are equipped with the coordinates, so casting events can be located exactly on the slab surface features. It is presented cases where the defects are related to the behaviour of the casting flux. The role of the casting flux is essential. With images of Reveal CAST new studies and findings are possible concerning the function of the flux. Statistics of the different defects is shown with the tools included in the Reveal CAST. Also other useful features are presented as a video concerning online operation.

Clean steel and clogging / 187

Thermochemical and kinetic modeling for the evolution of non-metallic inclusions during ladle refining and continuous casting processes

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High clean steels have been widely employed as automotive parts. However, the spinel inclusion, which is formed during the ladle refining process, has potential causes of nozzle clogging as well as of defects in products. Furthermore, the liquid oxide inclusion in the steel melt can be transformed to spinel during casting process. Hence, it is crucial to predict the inclusion evolution during the ladle refining and continuous casting processes. Thus, we recently developed the macro simulation module for the refractory-slag-metal-inclusion multiphase reaction, called 'ReSMI' reaction model by integrating the refractory-slag, slag-metal and metal-inclusion elementary reactions in order to predict the evolution of inclusions during the secondary refining process. Furthermore, the simulation model for prediction of inclusion transformation during the solidification of steel was developed by linking the Ohnaka model into the FactSage macro simulation. Ohnaka model was used for microsegregation calculation and the FactSage was used for calculation of chemical reaction, phase transformation and inclusion formation behaviour. From this combinatorial simulation, we can predict the inclusion evolution procedure during refining and casting processes.

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Influence of rice husk ash on the reoxidation of molten steel in continuous casting tundish

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Rice husk ash on the molten slag is usually composed of solid powder layer, sintered powder layer and interface between the molten slag and sintered powder layer in continuous casting tundish. Because the complicated reaction at the molten slag-sintered powder interface has not been well understood, we investigated the effect of rice husk ash on the reoxidation of molten steel as well as on the corrosion of magnesia refractory. The increase in the ratio of rice husk ash (RHA) to carry-over ladle slag (LS) resulted in the severe reoxidation of molten steel. The increase in the silica activity in the slag layer promoted the self-dissociation of SiO2 from the slag layer into the molten steel. Thus, the silicon and oxygen pick-up occurred as the RHA/LS ratio increased. The oxygen pick-up in the molten steel as well as a decrease in inclusion absorption behavior of molten slag by increasing the RHA/LS ratio caused the formation of Al2O3-rich inclusion in the steel. The spinel inclusions was also formed in the steel by the dissolution of Mg from the molten slag into the steel, which was promoted due to the corrosion of MgO refractory. MgO in the refractory directly dissolved into the slag layer without forming any intermediate compound layer (e.g. spinel) at slag-refractory interface. A slag flow potentially induced by the evolution of gas bubbles at the solid powder-slag-refractory interface accelerated the corrosion of MgO refractory with increasing RHA/LS ratio. Hence, the reoxidation of molten steel in tundish, which causes the formation of alumina-rich inclusions, as well as the corrosion of MgO refractory become more serious as the casting sequence increases.

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Impact of various refractory materials on the wear of stopper rods

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Steel cleanliness is a complex topic, which is influenced at almost every step in the production line. It starts on the liquid side in the converter and ends in the solidified slab, and is further topic to modification by heat-treatments or rolling. To produce and provide high quality steel, the steelmaker has to be able to control the inclusions in the as cast slab, where inclusions can range from the nano- to micro scale. In this work, the authors studied the influence of alumina, magnesia and MA-spinel refractories as a stopper rod material in a Ca-treated low carbon, high manganese steel. The stopper rods were recovered after a full casting sequence and are compared to virgin stopper rods. The experimental work consists of optical light microscopy, scanning electron microscopy, and computer aided surface analysis. While the alumina stopper rod shows a chemical reaction to the Ca-treatment, with the formation of various calcium-aluminates, the MA-spinel and magnesia stopper rods show only a minor chemical reaction zone.

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Continuous heat temperature measurement in the tundish

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The proposed paper describes the application of a measurement system (CasTemp® from Heraeus Electo-Nite) for observing the heat temperature in the tundish near the stopper continuously. The knowledge of the temperature in this region is essential for monitoring and estimating flow conditions in the tundish (and therefore making assessments on the separation behalf). Furthermore it's very helpful for controlling and optimizing the continuous casting process thus many caster process parameters are dictated by the tundish steel temperature. The occupational safety can be increased and maintenance costs can be decreased by preventing breakouts caused by too hot melts or avoiding the freezing of the submerged entry nozzle (SEN) determined by too cold melts. By the way not only temperature but also temperature gradient (concerning time) is a meaningful parameter. In the paper some measurement results are shown and interesting effects are discussed. Finally preliminary assessments for modelling the heat temperature in the tundish are considered.

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Determination of critical bath level in the tundish by physical modelling

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A level of steel in the tundish is changing during sequential continuous casting. The most significant decrease of the steel level occurs when replacing ladles. It is generally known that if the height of steel level in the tundish drops below a certain critical level, it may generate vortexes over the nozzles and as a consequence entrainment of tundish slag into individual casting strands can occur. Thus, it is necessary to identify the critical level of steel for specific operational conditions. In this paper, the methodology of physical modelling is described. Physical modelling was focused on the evaluation of current conditions of steel casting at the application of different impact pads in the tundish. An influence of different casting speeds on critical bath level was also evaluated.

Mold monitoring / 192

Analysis and optimisation of mould cooling conditions by application of CFD modelling and verification in industrial trials

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Against the background of the decisive role of heat transfer in the continuous casting mould for product quality a CFD model was developed, verified with industrial trials and applied for the adjustment of the cooling conditions in the mould. The numerical model included melt flow and solidification as well as a completely resolved cooling system, i.e. copper mould walls and cooling water flow. Coating of the copper plates, different layers of mould powder as well as a developing gap at the narrow face were considered with thermal resistances. In parallel

temperature measurements were performed using a fibre optical system as well as thermocouples. This large database was used to verify the numerical model for different mould formats as well as different steel compositions. Main objective of the work was the homogenisation of the heat transfer in the mould, i.e. in the meniscus area and the mould corners, using the local heat flux distribution, the overall wall heat flux and the maximum copper temperature as evaluation criteria. Systematic numerical simulation studies with several geometry modifications of the cooling system were performed and the local heat transfer was significantly optimised. Adaptions of the mould geometry and its influence on copper temperature and surface quality were examined in industrial trials.

Slab casting / 193

Industrial investigations of fiber optical sensor instrumented thick slab caster mould

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Increasing quality requirements on continuous casting products lead to the necessity of getting detailed information on physical phenomena occurring in the mould. Temperature measurements help to control the beginning solidification, e.g. with a sticker warning system. Up to now measurements with thermocouples are the state-of-the-art. An alternative is presented here with a fibre optical sensor system. This system shows a high resolution in space and time. Additionally less space is necessary in comparison to thermocouples. A thick slab mould was equipped with two sensor rows including 10 measuring positions each. In the meniscus area the distances between measuring positions were lowered, so the operator of the casting machine was enabled to monitor the meniscus precisely based on the temperature results. Overall two measuring campaigns were performed, one with the initial mould geometry and one with an adjusted mould geometry aiming at a homogenised heat transfer in the mould corners.

Slab casting / 196

New generation of continuous casting plants with intelligent manufacturing strategy

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Changing market situations demand sustainable usage of new available technologies to support steel producers with highly flexible plant configurations and tools. Therefore investments are focused to optimize production costs and product quality with short-term return. Modular design of upgrade solutions provides an individual configuration of metallurgical process-optimization respecting holistically the steel making and casting route.
One of the important developments in the last years is the integration of process parameters over the entire production route, starting from iron making till finishing process. This was also considered for casting plants through the usage of the chemical steel analysis data from secondary metallurgy as an input parameter set for the process model at the casting plant by DynaPhase phase transformation modelling. Target of use is to understand the steel grade perfectly in composition and to control the process accordingly with reduced process measuring efforts like measuring of final solidification at the strand for state of the art soft reduction.

Further a reduction of energy costs on the one hand while improving product quality on the other hand was in the focus of our new developments, which results e.g. in the completely new secondary cooling system DynaJet Flex. This system does not need anymore any operation air and increases the cooling turn down rate to double, which contributes to the growing demands in special steel casting.
This paper will give an overview beside the topics mentioned above on the new developments in continuous casting of the last two years with several results out of operation, as well as highlights on the Industry 4.0 setup of continuous caster process modelling with plant configuration.

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Primary cooling control for high-speed slab continuous casting up to 2.50 m/min

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The key technologies and development process for high speed casting technology were described by the study on the No.3 high-efficient slab caster of Shougang Jingtang Company. Within more than one year of technical research, some measures were applied to solve problems such as insufficient mold cooling, mold level fluctuation, and slab bulging. As a result, the casting speed successfully reached 2.5 m/min from 1.7 m/min for low carbon steel, and up to 2.0m/min for ultra-low carbon steel, with a slab section of 230×1650mm. In this paper, the characteristics of conventional slab mold heat transfer for high casting speed was also studied based on the practical historical data analysis, including mold cooling water temperate increment, the average heat flux and mold copper plate temperature variation. The mold average heat flux increased with the growth of casting speed, reaching nearly 2.05 MW • m-2 for wide face and 1.82 MW • m-2 for narrow face at a speed of 2.5 m/min. The minimum solidified shell thickness was above 12.3mm by model calculation. Also, a mathematical model for heat transfer and solidification in course of continuous casting slab was established to predict the solidified shell thickness at the mold exit. The shell thickness decrease with an increase in the casting speed, and the calculated thickness was about 12.3mm at a casting speed of 2.3 m/min. Through the in-depth study of the primary cooling process, it was beneficial to high speed continuous casting. The maximum casting speed reached 2.5m/min currently, and no breakout occurred during the high casting speed period.

Clean steel and clogging / 199

Research of clogging in continuous casting nozzles at KU Leuven

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Research of Clogging in Continuous Casting Nozzles at KU Leuven
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The continuous casting process accounts for more than 90% of the world's steel output and is considered to be a mature technology. However, a major problem of the process is nozzle

clogging, which increases the frequency of operation disruptions to change nozzles or tundishes or even to stop casting, rising operating cost, lowering productivity and directly resulting in a variety of quality problems. Clogging is a complex problem which has received a great deal of past study. These are: (1) identification of the clogging type of its formation mechanisms, (2) clogging detection and (3) approaches/ways for clogging reduction. In this abstract, we highlight some of our results that have been achieved in the research of clogging in continuous casting nozzles at HiTemp Group of KU Leuven. These include the followings: (I) characterization of the clogged nozzle from industrial practice to quantify extent/amount of the clogging and the identify causes of clogging. A distinct relationship was found between the amount of clogging and the cast steel weight. No relation between the amount of clogging and the superheating of the steel nor the steel flow rate was noticed. It was concluded that in practice, a given nozzle clog is often a combination of two or more of the different mechanisms, such as the transport of oxides present in the steel to the nozzle wall, steel reoxidation within the nozzle, chemical reaction between the nozzle refractory and the steel and others. (II) laboratory investigation of the interactions between the nozzle refractory, clogging materials, steel and slag to understand the influence of the chemical composition of the refractory material on the chemical compatibility with liquid steel, inclusions and slag, for better nozzle material selection and steel cleanliness. An experimental laboratory procedure was optimised to simulate the interaction behaviour during continuous casting. Al2O3 was found to give satisfactory results, and therefore a Al2O3 plasma coated Al2O3 carbon material was also tested in the laboratory with good results.
KEY WORDS: Continuous casting, Nozzle clogging, Inclusions, Refractory

Tundish / 201

Numerical analysis of influence of modern ladle shroud for hydrodynamic conditions of liquid steel flow in one strand slab tundish

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In the continuous steel casting process ladle shroud is used as a protective device or device developing the pattern of liquid steel and non-metallic inclusions motion. With the appropriate construction of ladle shroud, the hydrodynamic structure of liquid steel motion can be effectively modified in the tundish. The facility under investigation is a single-nozzle slab tundish. For the examined facility, two unique ladle shroud have been designed, whose purpose is to stimulate the motion of liquid steel within the working space of the tundish. Computer simulations of the liquid steel flow were done using the Ansys-Fluent computer program. The use of the modern ladle shroud in the tundish effectively influences the pattern of liquid steel flow.

Surface defects and postprocessing of slabs / 202

Slab stacking automation in the hot slab yard as key factor for postprocessing of cast slabs

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Automation in the hot storage yard is a difficult task in an interconnected environment where differently sized slabs with a wide range of follow-up destinations create a complex set of stacking rules. Slabs that are destined to move on to scarfing, trimming or warm holding need to be carefully arranged to stacks in order to avoid cracks or curved slabs. The constrained storage

space and the requirement for efficiently using material handling equipment (cranes, trailers, vehicles) on the other hand further complicate these decisions. In this work the authors will present an optimization model that is applied to the hot scarfing yard at voestalpine Stahl Linz. Results of the model are compared with past data and a pilot is implemented in a part of the hot scarfing yard. Focus of the paper will be the partition of the decision process into smaller optimization problems and their integrated solution. To conclude the paper the different possibilities of postprocessing of voestalpine Stahl are presented and discussed. In this section the focus is on the newly build scarfing machine which has gone in operation end of 2014

Mold flux technology I / 203

Innovative ideas for successful continuous casting of high aluminum AHSS

The demands for AHSS have gradually increased due to their ability to reduce vehicle weight as a means to save energy, and to reduce the environmental impact. However, the successful design of AHSS often require the addition of large amounts of alloying elements such as aluminum, which make it difficult to cast sound slabs without surface defects. When casting high aluminum AHSS, due to the reaction between aluminum in steel and silica in mold flux, the viscosity and crystallization characteristics of the mold slag changes drastically, and deteriorates mold lubrication. Therefore, it is critical to limit the reaction between Al in steel and mold slag and at the same time to provide consistent and adequate mold slag in-use properties. This study will describes two possible countermeasures for successful casting of high aluminum AHSS. Firstly, an innovative continuous casting process based on molten mold flux feeding technology will be introduced. In this process, molten mold flux is fed into the casting mold to enhance the thermal insulation of the meniscus and, hence, the lubrication between the solidifying steel shell and the copper mold. Enhancement of both the castability and the surface quality of high-aluminum advanced high-strength steel (AHSS) slabs is one of the most important advantages when the new process has been applied into the commercial continuous casting process. Secondly, development of non-traditional lime-alumina based mold fluxes which have the potential to reduce slag-steel interaction during casting of high aluminum AHSS will also be dealt. Several trial casts of 1.45% Al TRIP steel using the lime-alumina based mold fluxes have been critically assessed in terms of stability of chemistry and mold performances. The crystallization behavior of lime-alumina based mold fluxes has been investigated in order to clarify the effects of phase evolution, crystallization kinetics, and morphology on casting performance.

Tundish / 204

Investigation of cleanliness in two-strand tundish with different dams

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The paper shows the results of the research obtained by industrial experiments with use of different dams in the tundish. The number and distribution of the inclusions for different positions of ultra-low carbon steel slabs were also analysed by Aspex. The industrial experimental results showed that: the average inclusions at dam without hole and with hole in the tundish are distributed 31.66/cm2 and 167.70/cm2. The size of inclusions with 10-15μm, 15-20μm, 20-50μm and >50μm at dam without hole in slabs are distributed 25.82/cm2, 4.65/cm2,2.44/cm2, 0.11/cm2; the size of inclusions with 10-15μm, 15-20μm, 20-50μm and >50μm at dam with hole are distributed 37.92/cm2, 7.97/cm2, 3.66/cm2, 0.32/cm2. The number density of inclusions in the dam without hole zone was markedly less than that in other dam with hole zone. Keywords [U+FF1A] Two-Strand Tundish; dam; non-metallic inclusions; continuous casting

New developments / 205

New micro-mill concepts

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SMS group has extended its product portfolio to include the new Micro CSP® concept, at the heart of which is the vertical liquid bending type Micro CSP® caster, which is designed for the annual production of approx. 500,000–750,000 t low and medium carbon steel. The idea behind this development was to limit the system to essential equipment only, while simultaneously ensuring stable and reliable production, of course. This principle is evident in the configuration of the casting floor equipment, consisting of a ladle turret with rigid arms, a tundish car and cold tundish technology, followed by the strand guide system in the form of a single segment without drives and hydraulics. These efforts meant that the capital costs not only for the machinery but also for the building and infrastructure were reduced to a minimum. In addition, operating costs are reduced significantly thanks to the extremely compact design. The shorter distance between the mold level and furnace entry, in particular, plays a vital role here, as this enables high temperature casting, which in turn results in highly energy-efficient production. The Micro CSP® concept is perfectly suited for the growing production levels in emerging markets as well as for decentralized production in established markets that are just as cost-conscious.

Surface defects / 206

Study on transversal crack formation in Al-killed medium carbon steel by in-situ bending tests

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The In-Situ Material Characterization–Bending (IMC-B) test is a new laboratory method to evaluate the susceptibility of steel towards transverse crack formation in the continuous casting process. Samples are cast under near process conditions, cooled to bending temperature in a controlled way and finally bent in a 3-point bending test with a deflection of only a few millimeters, according to the conditions in the straightening area of a continuous casting machine. The maximum tensile strain is as well limited to only a few percent and both the re-crystallization as the deformation induced precipitation/phase transformation are suppressed. Surface oxidation is permitted and the initiation of defects at the surface along austenite grain boundaries is thus promoted. First result proved the correspondence of the characteristic of defects with those formed in the cc process and the significance of the results regarding the influence of bending temperature and alloying content. This work deals with the results of bending experiments on Al-killed medium carbon steel at temperatures of between 1100°C and 650°C. The thermal sequence is derived from slab casting conditions. The results prove the existence of a pronounced temperature range of low ductility at between 1000°C and 850°C. At the most critical temperatures a tensile strain of only 1.5 % is sufficient in order to form first transversal cracks. The number is increasing significantly at higher strains up to 6.5 %. The results are finally interpreted by precipitation kinetics. In future the results will mainly be used to verify quality functions for process models.

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Further development and validation of IDS by means of selected experiments

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IDS is a thermodynamic-kinetic-empirical tool for solidification, microstructure and material properties of steels, which has been developed at Aalto University in Finland since 1984. IDS calculates phase fractions, phase transformations and several solidification, cooling and reheating related phenomena, including inclusions and precipitates from liquid state to room temperature and during reheating. The present solutes available in IDS are C, Si, Mn, P, S, Cr, Ni, Mo, Al, Cu, N, Nb, Ti, V, Ca, B, O, Ce, Mg, H. The heart of the model is the large thermodynamic, diffusion and microstructure data bank made through our own assessment work. Particularly, the thermodynamic database of IDS has been clearly extended during the last years. IDS also includes many special modules, such as quality prediction, scale formation, gas behavior, material properties and austenite decomposition. The material property module was recently extended by adding new sub-modules of creep rate and elastic modulus, and the austenite decomposition module was extended with the effect of boron. The quality of the calculations depends significantly on the underlying thermodynamic data. A cooperation has been carried out with the Montanuniversitaet Leoben to further development and validate the IDS databases. A special research field at the Chair of Ferrous Metallurgy in Leoben is the identification of peritectic steel grades by means of DTA/DSC-measurements in the lab. Beside the investigation of the initial transformation behaviour (pure δ or γ, hypo- or hyper-peritectic) such measurements can be used to determine full phase diagrams. A new finding was, that the quite important silicon and manganese interaction in Fe-C-Si-Mn system was insufficiently described. A full section of a Fe-C-1Si-2Mn (wt.-%) system was investigated by systematic DSC measurements and this new results were implemented into IDS. The transversal cracking during continuous casting depends strongly on the austenitic grain size. the grain growth of selected Fe-C-1%Si-2%Mn alloys was investigate in-situ by high-temperature laser-scanning-confocal-microscopy (HT-LSCM) trials. The combined use of selected alloy variations, DTA/DSC-measurements and HT-LSCM observations are very beneficial tools to further develop and validate software tools like IDS, especially for new demanding steel grads.

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Continuous Casting between Hopes and Reality

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New developments in secondary cooling / 210

Experimental investigations on spray characteristics of water/air nozzles.

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In the secondary cooling zone of the continuous casting process the steel is cooled down by water and water/air nozzles. The cooling has to be sufficient enough to ensure a certain shell thickness and finally the complete solidification of the material. Further a controlled and uniform cooling strategy is important to minimize the amount of defects in the solidified steel. To determine the cooling characteristics of different nozzles at different operation parameters the Nozzle Measuring Stand (NMS) at Montanuniverstät Leoben is used. In the first part of this work the measuring principle of the NMS is explained. Secondly the influence of different cooling parameters is discussed. Therefor the water distribution and the heat transfer coefficient for a single nozzle type were measured using the NMS. To show the change in cooling intensity over the width of the spray, the HTC was determined at several positions. Of particular interest is the area of overlapping. In this point two sprays interact with each other what can lead to a significant variation in water distribution and HTC. The modified process parameters for this investigation were the nozzle distances, water flow, air pressure and casting velocity.

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Segregation measurements of slabs produced with soft reduction

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High requirements on the slab qualities necessitate optimized casting processes and high precise analytical methods. Determination of macro segregation using optical spark emission spectroscopy make possible fine adjustment of soft reduction in order to acquire optimal isotropic properties of hot rolled products. To account for the individual quality characteristics of main steel grade, voestalpine Stahl has established a procedure to optimize the soft reduction setpoints by static casting trials and consecutive investigations of metallographic samples. For such test sequences the soft reduction positions are kept constant (static soft reduction) and the point of final solidification is shifted by changing the casting speed. Samples are cut and investigated using OES-PDA (Optical Emission Spectrometry with Pulse Discrimination Analysis). Utilizing these results the optimum setpoints for soft reduction are determined.

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