THE 8TH INTERNATIONAL STEELSIM CONFERENCE

> 13–15 AUGUST 2019 > TORONTO, ONT., CANADA

SPONSORED BY

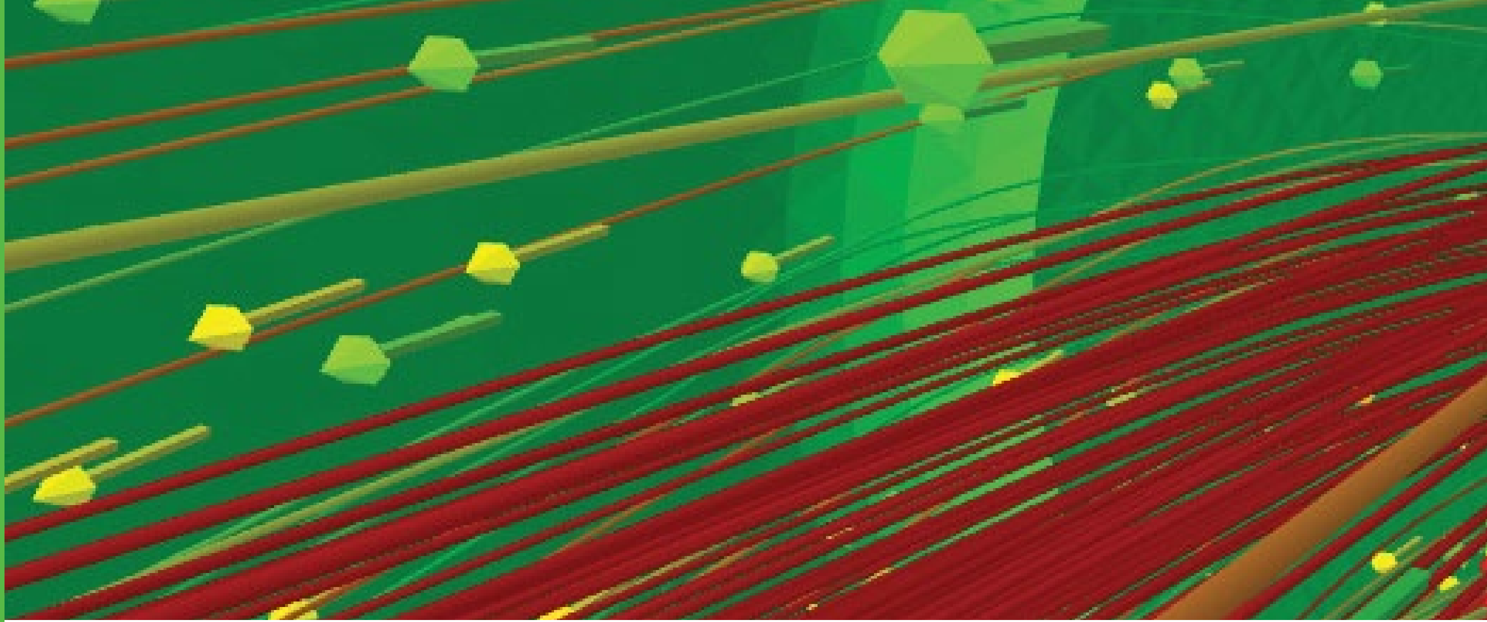
AIST's Computer Applications Technology Committee

Metallurgy and Materials Society (MetSoc) of the Canadian Institute of Mining, Metallurgy and Petroleum

ORGANIZED BY

Chenn Zhou
Steel Manufacturing Simulation and Visualization Consortium (SMSVC), Purdue University Northwest.

Scientific Program Committee



REGISTRATION FEES

> Advance Registration
before 2 July 2019

Member
US$1,095

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US$1,310

> Registration
after 2 July 2019

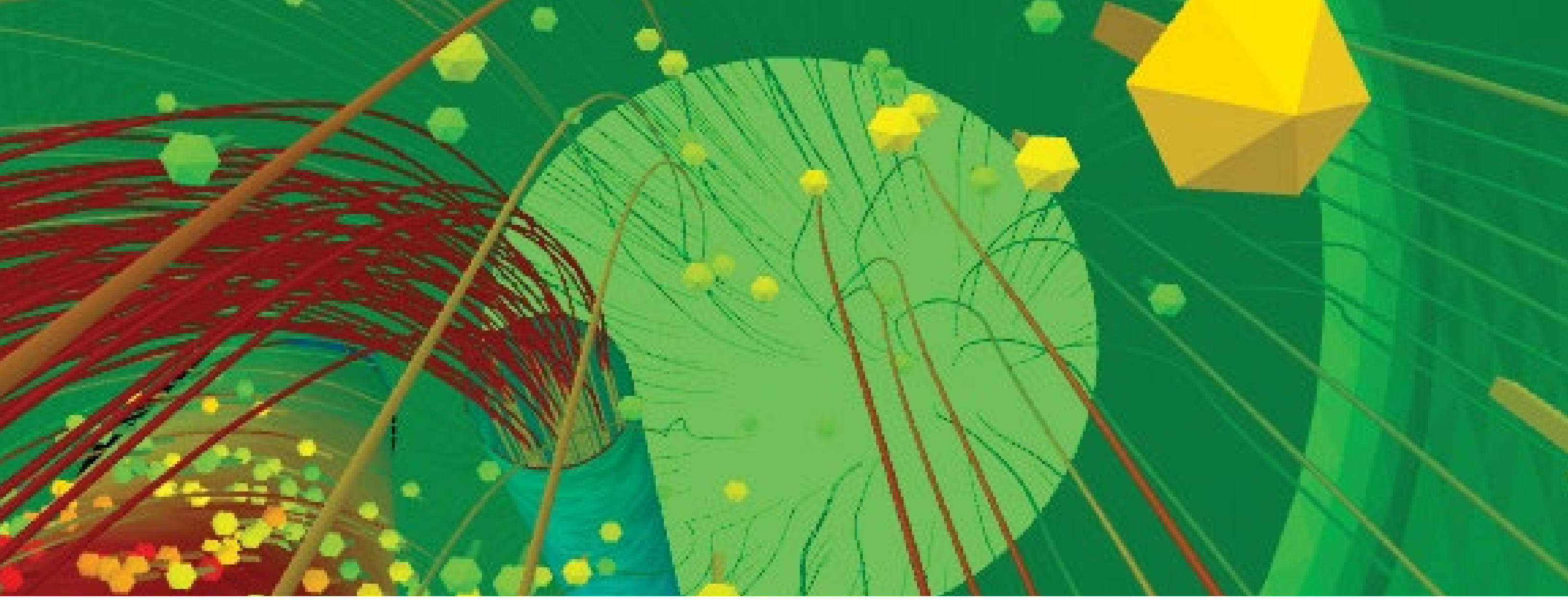
Member
US$1,195

Non-Member
US$1,410

Student rate available.

HOTEL ACCOMMODATIONS

A block of rooms has been reserved at the Marriott Downtown at CF Toronto Easton Centre, Toronto, Ont., Canada. Please call the hotel at +1.800.228.9290 by 15 July 2019 to secure the AIST discount rate of CDN$252 per night for single occupancy.



ABOUT THE PROGRAM

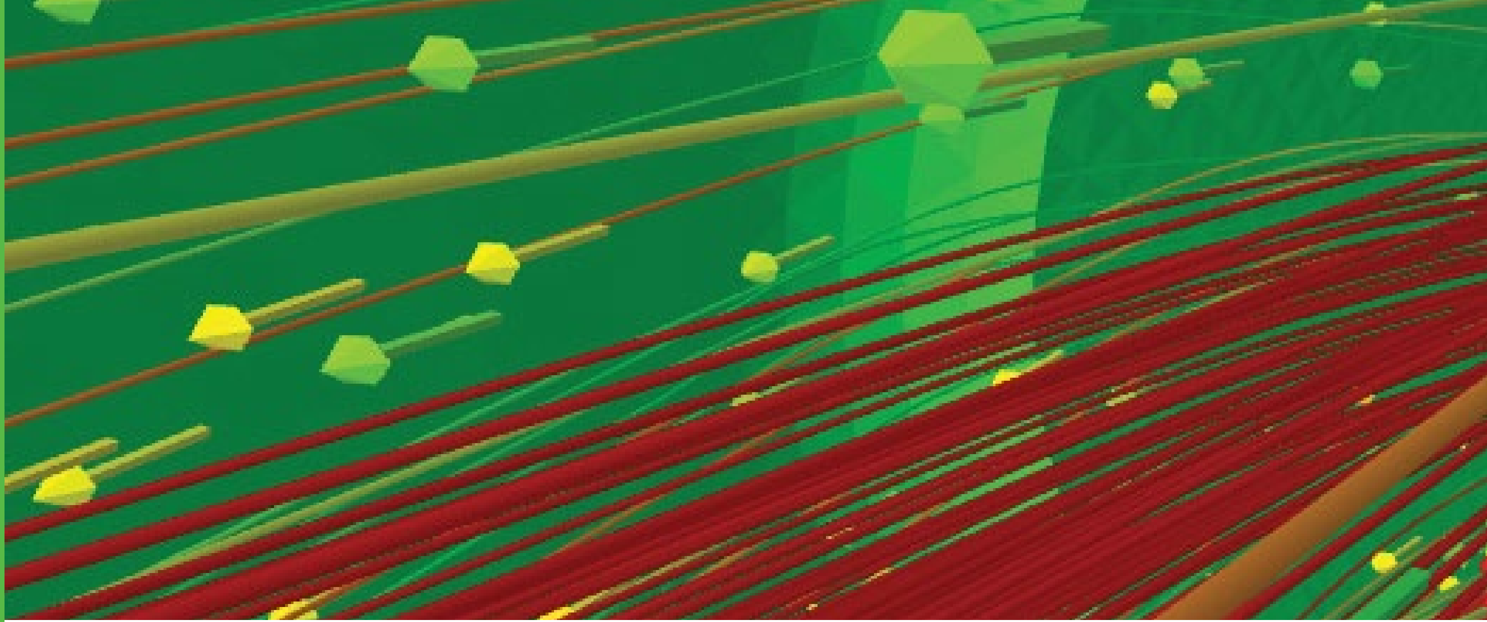
The important role of modeling and simulation of metallurgical processes has achieved worldwide acknowledgment, especially in optimizing technological processes, reducing production costs and increasing steel quality. Powerful computational methods provide an in-depth understanding of experimental findings and guide further experimental work. Modeling and simulation promise possible solutions, even breakthroughs, for the future development of the steel industry.

STEELSIM 2019 will be an excellent venue for producers, academia, researchers and engineers from around the globe to exchange recent developments and information on issues related to modeling and simulation of metallurgical processes. We welcome you to participate in this advanced conference and are looking forward to meeting you in the summer of 2019.

ASSOCIATION FOR IRON & STEEL TECHNOLOGY

MET SOC

CIM ICM



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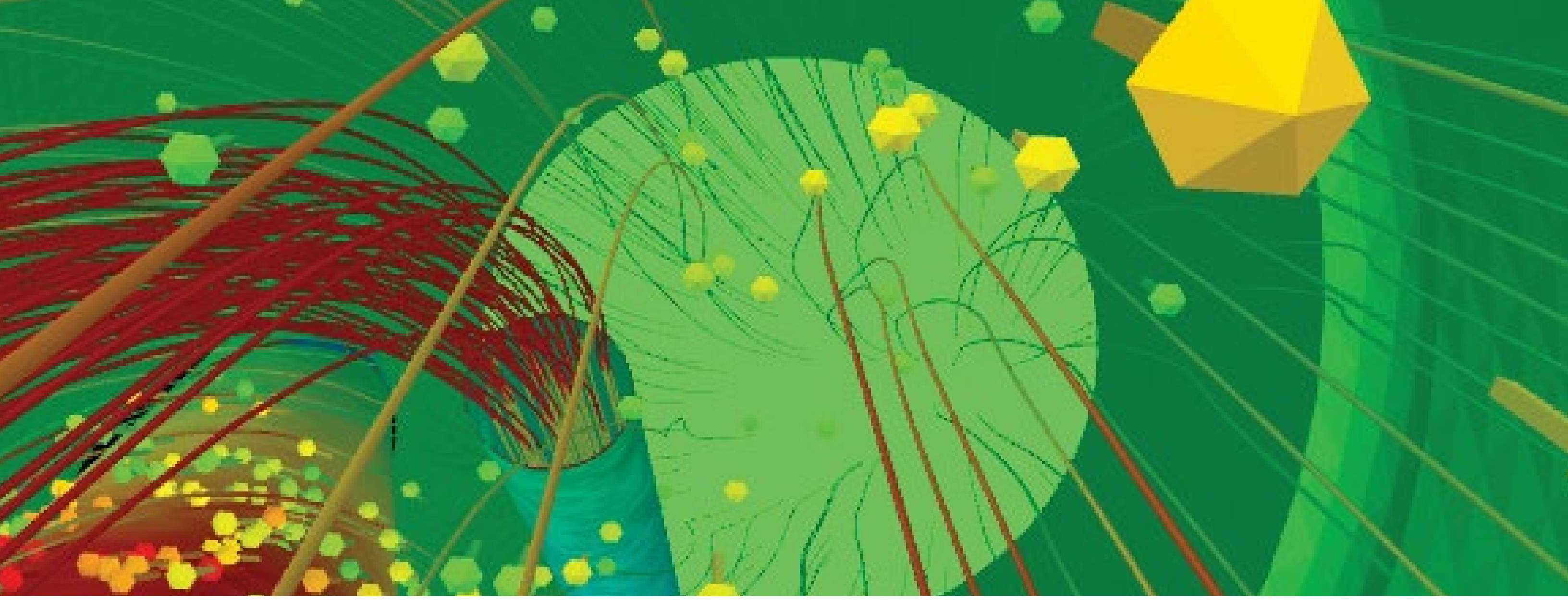

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Chenn Qian Zhou
Purdue University Northwest, USA (Chair)

SCHEDULE OF EVENTS

✦ = Keynote Presentation

TUESDAY, 13 AUGUST 2019

8 a.m. **Opening Remarks**

C. Zhou, Purdue University Northwest

8:15 a.m. **Plenary Lecture: Data, Modeling and Time in Smart Manufacturing**

J. Davis, University of California, Los Angeles

Today's manufacturing economy is demanding higher productivity, performance and precision to produce more purpose-built products and materials that are manufactured faster with zero incidents. Products and processes need to remain environmentally neutral and use far less energy and material. Higher precision requires products and processes in which micro and macro effects are more tightly coupled to optimize and qualify product properties while the product is made. Higher productivity involves bridging silos and verticals in supply or value chain enterprises to facilitate interoperability, demand response, and optimize upstream and downstream effects. Higher performance involves better operating conditions and control and/or management of risks and constraints.

Smart manufacturing in the U.S. comprises the business, technology, workforce and organizational practices for restructuring highly compartmentalized manufacturing value and supply chain enterprises to effectively use secure data, modeling and time, where, with whom and when they are needed with the right technology to achieve full business potential. In smart manufacturing data, modeling and time are symbiotic. Data are anything digital that can be networked, orchestrated and analyzed; modeling includes all forms using, building from and generating data to take automated or human action; and time defines the operational benefit of an action to the physical manufacturing enterprise. Data become the new currency; time is value; modeling extracts the value; and smart manufacturing orchestrates the generation, application and distribution of intelligence, and opens the door to operational self-interrogation and new ways of involving smart workers for action at the right time.

By radically lowering data and modeling cyber infrastructure costs, accelerating development of applications, and organizing them for reuse, manufacturers of all sizes have access to technologies and practices to stimulate business and growth opportunities. Potential economic gains are so substantial they stimulate significant reinvestment, job growth and technology growth. Business can change to achieve greater product precision locally, often in smaller lots, but with extended upstream and downstream interoperability and global orchestration. Demand-dynamic responsiveness becomes an advantage — the antithesis of simply reducing market volatility. Economic/reinvestment gains are outcomes of higher productivity, fewer defective products, and better use of energy and materials.

TRACK A

SESSION A1: Ladle Desulfurization & Refining

9:20 a.m. Technical Limitations for Developing a Practicable LMF Desulfurization Model✦

D. Liao, S. Holko, A.S. Moreno, K. Boylan, ArcelorMittal Dofasco G.P.

Desulfurization is an important function of ladle metallurgy, and is an expensive, time-consuming process. Although there are many desulfurization models published and implemented in practice, reliable and practicable models are rare. The reasons for poor model performance cover both theoretical and practical issues. Regarding theoretical problems, in traditional models the thermodynamic calculations of oxygen activity (a[O]) and of slag sulfide capacity (CS) are insufficient, which causes improper estimation of sulfur partition in slag and steel (Ls). In addition, some assumptions regarding desulfurization kinetics are incomplete. The mass transfer coefficient (keff) in the kinetic model is not only related to the stirring power (w), but is also significantly impacted by slag physical properties such as viscosity. In addition, properly scaling the stirring power to calculate the mass transfer coefficient is also critical for developing a proper ladle metallurgy desulfurization model. This paper describes an improved model for steel ladle desulfurization.

TRACK B

SESSION B1: Rolling & Reheating Simulations

Dynamic Downstream Processing of Steel

N. Chandra Gourain, A.N. Bhagat, A. Ranjan, S. Biswas, Tata Steel

Rolling of continuous-cast steel maintains a particular time-temperature rule to achieve desired mechanical properties of the steel grade. Any variation in upstream steel composition and the downstream rolling process leads to a cumulative deviation in the mechanical properties of the steel grade after rolling. To reduce such variations in mechanical properties, response of all steel composition and rolling parameters has been statistically modeled and counterbalance of the deviation in upstream steel chemistry is imparted during downstream process parameters. This dynamic on-line control of the rolling process has been implemented through the existing level 2 and level 3 production automation system. After applying this novel method of dynamic rolling, the variation of its mechanical properties has been narrowed down to 50% of its normal production process.

TRACK C

SESSION C1: Downstream

Lifetime Improvement of Radiant Tubes Using Structured Steel Sheets✦

D. Brykarczyk, RWTH Aachen University; A. Neumann, BTU Cottbus Senftenberg; W. Lenz, H. Pfeifer, RWTH Aachen University; M. Bambach, BTU Cottbus Senftenberg

In industrial furnaces, radiant tubes used for heating are critical components. The radiant tubes, which contain a gas burner, are used for separating the oxidizing gas from the atmosphere. An industrial funaces used, e.g., for heat treatment of strip steel, consists of several hundreds of radiant tubes. The main reason for early failure of the radiant tubes is significant stress due to temperature gradient over the radiant tubes. The recent project evaluated the effects of hexagonal structures for the construction of radiant tubest to extend lifetime. A combined computational fluid dynamics-computational structure dynamics simulation calculates the max stresses, creep strain and deformation to make estimations of the improved lifespan. Hexagonal structures should reduce the failure mechanisms caused by mechanical stress. The simulation results are validated with measurement data from a test station for radiant tubes. A test tube with a hexagonal structure is compared with a traditional tube without a structure. The results will be transferable for a wide number of industrial components.

	TRACK A	TRACK B	TRACK C
	SESSION A1 (cont'd)	**SESSION B1 (cont'd)**	**SESSION C1 (cont'd)**

9:45 a.m.

Prediction of Mass Transfer in Hot Metal Reactors

P. Gardin, L.D. de Oliveira Campos, ArcelorMittal Global R&D; S. Vincent, Universite Paris Est.

To control both slag and hot metal compositions, it is important to have a local description of the flow at the interface between the two phases. The paper explains the methodology that was used to have such a description and discusses the main steps for the validation, from water model with an oil layer at the top to the hot metal process. First application concerns the continuous casting mold to predict the time evolution of slag composition; it also provides information to quantify the effect of slag viscosity on both local flow near the interface and mass transfer. The second application investigates the influence of gas bubbles on mass transfer and explains how they lead to a very heterogenous slag composition.

Applications of FEM Simulation to Roll Pass Design and Rolls Stresses Analysis

N. Poulain, Transvalor Americas Corp.

Simulation of rolling of long products has grown tremendously in recent years in the steelmaking industry. FORGE® has demonstrated its capability to accurately predict material flow and avoid passes overload. However, the analysis of the stresses in the rolls has not been a major concern. Since rolls are expensive, the next step in simulating the rolling process is to predict the risk of breakage and estimate the wear of the rolls. Simulation is key in this analysis. This presentation shows examples of roll pass design analysis through simulation and investigates the influence of the cooling system positioning on the rolls' stresses and wear.

Modeling the Microstructure-Dependent Fracture Toughness of Quenched and Tempered Steels

J. Hu, Z. Guo, N. Saunders, Sente Software Ltd.

Fracture toughness (KIC) has been widely used to assess the ability of a material to resist fracture. For quenched and tempered steels, KIC depends on the austenitization and tempering conditions. Complexity exists due to the occurrence of tempered martensite embrittlement. It is beneficial to develop computer-based models that can calculate the KIC of steels at different tempering conditions to reduce the experimental cost. This study explores the feasibility of implementing two analytical models respectively for cleavage and ductile fracture for the evaluation of KIC of quenched and tempered steels. The models are correlated to the microstructure information calculated in JMatPro®, such as grain size and fraction of precipitates after quenching and tempering, as well as interparticle spacing after tempering. This approach has been validated against extensive KIC data of steels over a wide range of austenitization and tempering conditions. The methodology can ultimately aid the materials processing and structural integrity assessment.

10:10 a.m.

Analysis of Transport and Removal of Inclusions in an Industrial Gas-Stirred Ladle

W. Liu, X. Guo, A. Silaen, N. Walla, Purdue University Northwest; H. Oltmann, A. Bhansali, A. Pitts-Baggett, V. Thapliyal, E. Pretorius, Nucor Steel; C. Zhou, Purdue University Northwest

A full-scale and unsteady three-dimensional computational fluid dynamics (CFD) model has been developed based on an operating ladle used by Nucor Steel. The CFD–Population Balance model (PBM) coupled method has been proposed to investigate the inclusion behavior, including inclusion growth, bubble collision, inclusion removal by attaching refractory, capturing by top slag and capturing by bubble. The phenomena of inclusions' turbulent random motion and bubble-inclusion buoyancy collision were considered. The numerical model was validated with the flow field of industrial ladle. A parametric study of the gas bubble size and argon gas flowrate were conducted.

Effect of Intercritical Annealing on Retained Austenite and Properties of a Low-Carbon 3Mn Steel

Z. Xie, Y. Yu, G. Han, C. Shang, University of Science and Technology Beijing

The influences of intercritical annealing (IA) temperature and time on retained austenite and properties were investigated in a low-carbon steel containing 3 wt.% Mn. Results showed that the multi-phase microstructures consisted of intercritical ferrite, martensite/bainite, retained austenite and fine dispersed precipitations. The volume fraction of retained austenite reached a maximum value of 14% after IA at 680°C for 30 minutes. Retained austenite was stabilized by the intercritical partition of Mn and Ni into the reverted austenite. The partition behaviors of Mn and Ni during intercritical annealing were studied by STEM. The austenite reversion behavior from low-carbon martensite and partitioning of alloying elements were discussed based on DICTRA simulations. Due to the combined contribution resulting from retained austenite and nanoscale precipitation, the excellent properties of high yield strength (751 MPa), low yield to tensile ratio (0.77) and ductility (12% and 25% in uniform and total elongation) were achieved after the IA at 680°C for 30 minutes.

Development of HSLA Cold-Rolled Steel Sheet (Yield Strength Higher Than 420 MPa, Tensile Strength Higher Than 590 MPa) at JISCO Steelmaking Plant

C. Guarnaschelli, RINA Consulting - CCM S.p.A.; Z. Xiaolong, L. Jipeng, Gansu JISCO Group Hongxing Iron & Steel Co. Ltd.; A. Saccocci, P.E. Di Nunzio, R. Tonelli, RINA Consulting - CSM S.p.A.

High-strength, low-alloy (HSLA) steel sheets are used in many applications, e.g., automotive, where high mechanical strength and good ductility are required. The development of a cold-rolled HSLA steel sheet was carried out experimentally at CSM (Rome) and at JISCO plant in Jiayuguan, China. Manufacturing process includes thick-slab continuous casting (CSP), hot rolling, cold rolling, batch annealing and finishing. The alloy design started from literature and included an experimental phase on laboratory heats cast by vacuum induction melting, pilot-scale hot rolling and cold rolling, and annealing in a laboratory furnace. The definition of process conditions was supported by thermomechanical and recrystallization models. Continuous casting represents a primary issue, as steel composition is close to peritectic, with possible effects on surface quality and risk of breakouts. Industrial trials on 1.5-mm coils allowed to tune the operating practices, obtaining the mechanical strength ranges required for EU steel grade HC420LA (EN 10268) and Japanese grade JSC590R (JFS A 2001).

10:35 a.m. Refreshment Break

TRACK A

SESSION A2: Blast Furnace Modeling I

11 a.m.

Effect of an Angled Runner on the Fluid Flow in the Ingot Casting Process

J. Yin, M. Ersson, P. Jönsson, KTH Royal Institute of Technology

The present study considers an angled runner with the purpose of decreasing the velocity in the runner system during the initial stage of filling.

11:25 a.m.

Numerical Simulation of Temperature and Stress Field Distribution inside the Furnace Tuyere

C. Sun, Chongqing University

Furnace tuyere has a great impact on the smooth operation in the high temperature practical production. The design of tuyere water cooling system is of great significance for extending the lifetime of the tuyere. This study establishes a three-dimensional mathematical model of a tuyere, the temperature distribution and the companying stress distribution are simulated respectively under the preset conditions. The results show that the cooling water protects the large cavity inside the tuyere. However, the small cavity locates in the front end of the tuyere suffers the most serious conditions. The highest temperature could reach 410 K, which causes the stress to be determined as great as 312 MPa.

TRACK B

SESSION B2: Rolling & Reheating Simulations

11 a.m.

Analysis of the Effects of Oxygen Enrichment in a Reheating Furnace

B. Worl, J. Fan, A. Silaen, Center for Innovation Through Visualization and Simulation, Purdue University Northwest; J. Cox, ArcelorMittal USA; K. Johnson, ArcelorMittal Global R&D; L. Fabina, ArcelorMittal USA; J. Maiolo, K. Tian, Praxair Inc.; C. Zhou, Center for Innovation Through Visualization and Simulation, Purdue University Northwest

Reheating furnaces use an energy-intensive process to bring steel slabs up to a desired rolling temperature. In order to increase the efficiency of a reheating furnace, oxygen enrichment and oxy-fuel technology can be utilized. Oxygen enrichment is the process of increasing the amount of oxygen found in the combustion air beyond the naturally occurring 21%; this technology is easily implemented on active reheating furnaces. Using computational fluid dynamics, oxygen enrichment and changes in the amount of the oxidant can be studied for their effects on efficiency, productivity, combustion characteristics and scale formation.

11:25 a.m.

Redefining Warm Charging Rules at ArcelorMittal Dofasco

A. Chang, J. Fitzpatrick, A. Lanos, A. Cheung, D. Colbert, G. Gebara, ArcelorMittal Dofasco G.P.

At hot strip mills, some high-strength steel grades must be warm-charged into reheating furnaces due to the risk of crack formation caused by thermal stresses. If these crack-sensitive high-strength slabs cool below the minimum charging temperature, the slabs cannot be charged into the reheat furnace and thus are scrapped because of the high risk of cracking or even breaking during reheating. In order to increase scheduling flexibility and reduce the scrap rate, finite element thermomechanical models were developed to study the temperature and stress distributions during cooling and reheating. Based on simulation results and historical data, the minimum charging temperatures of high-strength slabs were determined and implemented at ArcelorMittal Dofasco G.P.

TRACK C

SESSION C2: Solidification

11 a.m.

Coupled Thermodynamic and Kinetic Fundamental Simulations of Casting Processes

N. Andersson, M. Ersson, KTH Royal Institute of Technology

A new dynamic model that describes chemical reactions, mass transfer, heat transfer and solidification is presented in this paper. The model uses computational thermodynamics for calculation of local equilibria and computational fluid dynamics for conservation of mass, momentum and energy. The model is exemplified for different solidification cases and the results are compared with experimental data. The aim is to create a flexible tool to be used with computational fluid dynamics for future process models.

11:25 a.m.

Large Eddy Simulation of Multi-Phase Flow Under the Effect of Electromagnetic Stirring

X. Li, B. Li, Z. Liu, R. Niu, Northeastern University

A three-dimensional transient large eddy simulation model is established under the effect of mold electromagnetic stirring. The turbulent flow field is calculated by Smagorinsky-Lilly model. An enthalpy-porosity technique is adopted to describe the growth of solidified shell. The movements of three phases are described through the volume of fluid approach. The rotating magnetic field is calculated through Maxwell's equations. Results reveal that the slag-metal interface is obviously transient and non-uniform with a significant vortex core near the center of this bloom. The slag-metal interface rises dynamically near the solidification shell and sinks near the center of the bloom, forming a typical tornado-like slag-metal interface in the mold. The reason for this shape of slag metal interface is due to the vortex flow caused by the rotating electromagnetic field and the injection of melt from the submerged-entry nozzle. The predicted interface is compared with previous experiment, and good agreements are obtained.

TRACK A

SESSION A2 (cont'd)

11:50 a.m.

Effects of Lance Configuration on the Flow and Combustion Behavior of a Pulverized Coal Plume in the Tuyere

D. Wu, P. Zhou, H. Yan, R. Zhu, Central South University; C. Zhou, Purdue University Northwest

To improve combustion efficiency and reduce lance and tuyere erosion, the combustion process of pulverized coal in the blowpipe was simulated. Four parameters, which are lance diameter, lance insertion angle, and horizontal and vertical distance from the lance tip to the tuyere tip, were investigated by assembling them into six types of lance configurations. Detailed information about the coal combustion and the gas-particle mixture flow characteristics were extracted and analyzed from a viewpoint of coal plume in the blowpipe, including the plume diffusion angle, the difference between the average temperature of the coal plume and the onset combustion temperature, and the decay of the main coal plume along the axial direction. The results show that the horizontal distance from the lance tip to the tuyere tip is the most sensitive factor that affects particle combustion performance in the way of changing the residence time for heat exchange.

TRACK B

SESSION B2 (cont'd)

Modeling of Heat Transfer During Controlled Cooling of Thermomechanically Treated Rebars Using Computational Fluid Dynamics Approach

R. Agarwal, M.K. Singh, S. Ghosh, B. Ghosh, R. Shankar, P.V. Thampi, Tata Steel Ltd.

Thermomechanical treatment (TMT) rebars are produced by the Temp-core process, which involves an "in-line" heat treatment in which hot-rolled bar is passed through waterboxes where it is quenched under high-pressure water jets. The quenching rate controls composite structure consisting of pearlite-ferrite, bainite and tempered martensite (from core to rim), which provide strength and ductility. The TMT process is difficult to model as it brings a multitude of complex physics such as heat transfer with film boiling (temperature above Leidenfrost point), highly turbulent fluid flow and multi-phase flow present in the control volume. A coupled heat transfer and fluid flow model based on computational fluid dynamics has been developed at the product technology division of Tata Steel, India, which predicts temperature profile and percentage martensite rim thickness of rebar during quenching process. The model has been validated with 16 mm rolling of NBM plant of Tata Steel Ltd., India.

TRACK C

SESSION C2 (cont'd)

Influence of Non-Uniform Temperature Distribution of the Mold on Solidification Behavior in Large-Sized Steel Ingots

C. Zhang, A. Loucif, R. Tremblay, M. Jahazi, École de technologie supérieure

The intensity of macrosegregation was found to be greatly influenced by casting conditions. In industry, large-sized steel ingots are often cast inside pits close to a wall or other ingots due to the limitation of time and space. These special constraints could result in non-uniform temperature distribution inside the thickness and along the height of the mold. Such non-uniformities may induce different solidification patterns, thereby affecting macrosegregation severity and extent in cast ingots. In the present work, the influence of non-uniform temperature distribution on macrosegregation of a 40-MT steel ingot was simulated in a 3D model using commercial Thercast® software. Boundary conditions were established according to the actual industry casting assembly system and fabrication conditions. Steel properties were determined by a combination of experimental works and thermodynamic Thermo-Calc® software. The predicted results were verified with the experimental measurements and discussed in the framework of diffusion and solidification mechanisms.

12:15 p.m. Refreshment Break

TRACK A

SESSION A3: Blast Furnace Modeling II

1:15 p.m.

On-Line Estimation of Liquid Levels and Local Drainage Characteristics in the Blast Furnace Process

M. Helle, M. Roche, H.H. Saxén, Åbo Akademi University

The paper presents a mathematical model for on-line estimation of liquid levels in the blast furnace hearth. The model is based on estimates of the production rates and measurements of the outflow rates of iron and slag using a subdivision of the hearth into different parts representing the regions drained by the tapholes. To prevent accumulation of errors caused by measurement and model uncertainties, an automatic correction scheme is developed. The corrections not only prevent the liquid level estimates from excessive drift, but also provide information about the local conditions at the draining tapholes, including estimates of the state of the coke bed in front of the taphole. The performance of the model is illustrated on data from a three-taphole blast furnace, and the ability to track the liquid levels and the internal conditions of the deadman in the different regions of the hearth is demonstrated. Analysis of the results reveals interesting findings about the drainage of the furnace and about how the conditions evolve with time when the operating tapholes are changed.

TRACK B

SESSION B3: Microstructural Effects on Product

Digital Quantitative Rating Method of Centerline Segregation and Its Influence on Variability in Mechanical Property of Corresponding Strips

F. Guo, W. Liu, X. Wang, J. Zhao, C. Shang, University of Science and Technology Beijing

The objective of this paper is to study the influence of centerline segregation degree of continuously cast slab on variability in mechanical property of X70 pipeline steel. Three rating methods were used to evaluate the segregated degree of two groups slabs and its effect on the properties of corresponding strips. The results indicated that the Mannesmann rating method was more suitable for rating segregation degree that had a direct relationship with strength and toughness. The segregated degree (from class 2 to class 3–4) rose one level, the tensile strength increased ~100 MPa, ductile-brittle transition temperature decreased ~30°C, and microhardness in the segregated region increased ~100 HV. Microstructure indicated the centerline segregated area from a sample with class 2 was dominated by ferrite, while lath bainite/martensite was observed when its segregated degree was class 3 or higher. Moreover, electron probe microanalyzer results showed Mn was enriched in the segregated area when the segregated degree was higher than class 3.

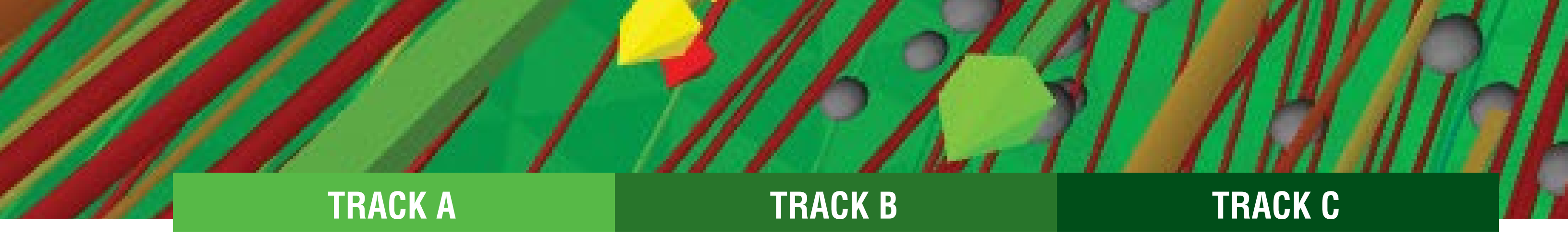
TRACK C

SESSION C3: Fluid Flow Simulations

Fluid Flow and Solidification Behavior in Slab Continuous Casting With Secondary Electromagnetic Stirring✦

D. Jiang, M. Zhu, L. Zhang, University of Science and Technology Beijing

A numerical model was built to simulate the transport phenomena in the slab continuous casting process with secondary electromagnetic stirring. In the model, the columnar region was treated as a porous zone and the Darcy law was used to calculate permeability, while for the equiaxed zone, a variable apparent viscosity was applied to simulate the fluid flow at the initial solidification stage. The model was validated by the measured data of slab surface temperature and magnetic induction intensity. The results show that solidification behavior near the 1/4 width of slab is postponed, due to the injected flow from the submerged-entry nozzle. With the rotational stirring mechanism used, the uneven solidification end can be improved, and it will become more obvious with higher current intensity. With the liner stirring mode applied, liquid moves in the transverse direction and the solidification at one side of slab is postponed.



TRACK A	TRACK B	TRACK C

1:40 p.m.

SESSION A3 (cont'd)

Simulation and Experiment Studies on Porosity Radial Distribution of Coke Layer in Blast Furnace Furnace Throat

H. Wei, M. Li, X. Tang, Y. Ge, Shanghai University; W. Liu, China Metallurgical Industry Planning and Research Institute; Y. Yu, Shanghai University

The porosity of layers influences the chemical reaction of gas and solid particles in the shaft and smooth operation of a long campaign in a blast furnace (BF). Thus, radial porosity distribution (RPD) of burden at the throat of the BF was studied by an adjustment charging system. The results showed that RPD of burden with different particle size distributions illustrates a symmetrical structure along the vertical line of a blast furnace. The porosity is the highest at the center and is around 50% (volume/volume) when the coarse cokes increases in the coke layer; the porosity at the center increases and the fluctuation of RPD becomes more remarkable. RPD in simulation is close to the experimental results and are far greater than RPD in simulation by virtual units due to a wall effect.

SESSION B3 (cont'd)

Effect of Multi-Stage Deformation During the Pipe Processing on Mechanical Properties of Steels Strength Grade X70-X80

A. Chastukhin, Vyksa Steel Works

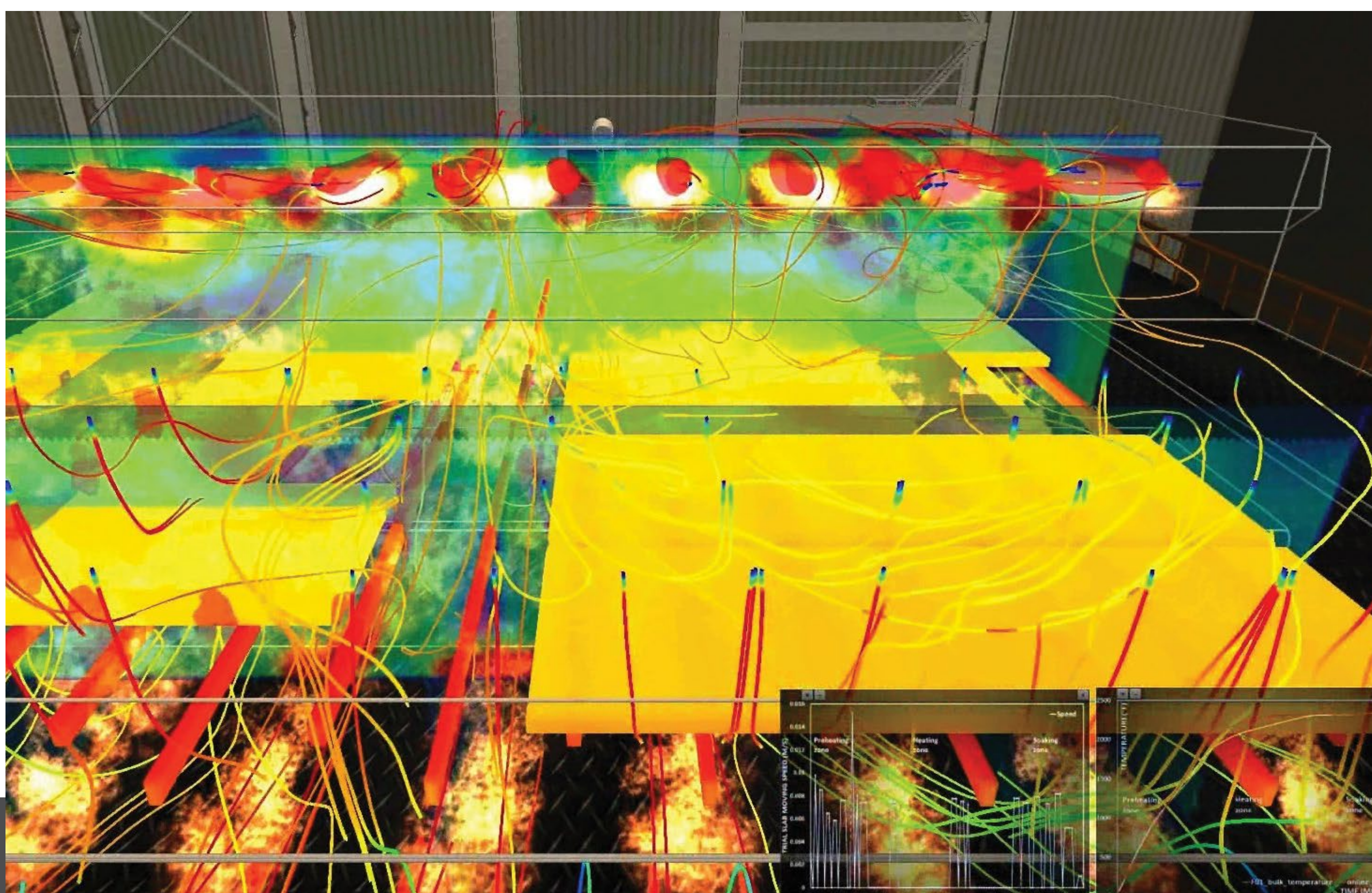
In this paper, the effect of pipe manufacturing on changing the mechanical properties of metal was investigated. A deformed state of metal during pipe manufacturing was analyzed. Transverse and longitudinal tensile samples were extracted from the centerline position of 10 different compositions of hot-rolled plates. More than 2,000 samples were tested at the MTS machine. After analyzing the tests results using the methods of regression analysis, a model was created that can predict properties of different strength grades and various sizes of pipes from the stress-strain curves of the samples from the plate.

SESSION C3 (cont'd)

Numerical Modeling of Optimized Two-Inlet TurboSwirl Device During Ingot Casting Process

H. Bai, Y. Liu, M. Ersson, P. Jönsson, KTH Royal Institute of Technology

In the casting process, the swirling flow can be applied to help the liquid steel form a more uniform flow pattern, which results in better internal structure and surface quality of the steel product. A new swirling flow generator has been investigated recently for both continuous and ingot casting processes. It has been shown that it can reach a similar effect in a more economical way compared to the traditional methods for generating swirling flows. High-swirling flows can also lead to instabilities of the liquid flow, so a two-inlet device is introduced in order to reduce the effect of asymmetry in the flow structure of the original device. A much calmer flow can be obtained by using the two-inlet device. Furthermore, a significantly decreased fluctuation frequency of the axial velocity and wall shear stresses can be reached. The structure of two-inlet device is optimized based on a previous study by adjusting the flaring angle of the convergent nozzle. The optimization is performed by ANSYS Design of Experiment and Optimization tools that can optimize the structure through an automatic parametric analysis. With the combination of optimized angle and two-inlet device, the results show a much more beneficial flow pattern compared to a previous study of original design.



TRACK A — SESSION A3 (cont'd)

TRACK B — SESSION B3 (cont'd)

TRACK C — SESSION C3 (cont'd)

2:05 p.m.

Track A

Development and Application of Mathematical Models to Simulate Liquid Phase Accumulation, Drainage and Heat Transfer in Blast Furnace Hearth

H. Upadhyay, Jindal Steel & Power Ltd.; T.K. Kundu, Indian Institute of Technology

The ability to predict the hot metal temperature variation during the tapping process is extremely useful since it gives a clear picture to the operator about the tapping operation and prevents any panic. At the same time it allows the correction of process parameters in case of any major deviation. If the metal temperature is too high or too low, it may directly affect the process and cost efficiency of blast furnace (BF) as well as basic oxygen furnace (BOF) plants. The control of hot metal/slag accumulation, drainage pattern and tapping temperature is of great importance in order to optimize the BF process and make it productive, energy-efficient and cost-competent. Therefore, it is of utmost importance for furnace operators to understand the mechanisms governing the liquid flow, accumulation, drainage and heat transfer between various phases in the BF hearth. As it's extremely difficult to carry out any direct measurement due to the hostile conditions in the hearth with chemically aggressive hot liquids, estimation and simulation based on rules of physics and mathematical calculations, taking into account available operating parameters, is the only viable solution. The objective here is to develop a mathematical model to simulate the variation in hot metal/slag accumulation and temperature during the tapping of the furnace based on the computed drainage rate, production rate, mass balance, heat transfer between metal and slag, metal and solids, slag and solids, as well as among the various zones of metal and slag itself.

Track B

New Efforts on Establishing a Toughness-Microstructure Relationship for Coherent Phase Transformation in High-Performance Steels Via Integrated Crystallographic Characterization

Z.Q. Wang, X.L. Wang, C.J. Shang, University of Science and Technology Beijing

Since microstructure is intrinsically crystal, establishing the direct toughness-microstructure relationship might be troublesome by traditional analysis as it emphasizes mostly on the microstructure morphology, not to mention digitally describing the quantitative relationship. In this article, the authors made a new effort on it by systematically proposing an integrated crystallography characterization methodology of the microstructure for coherent phase transformation. It consists of: (I) the determination of orientation relationship and the orientation of parent phase; (II) the configuration manner of CP/Bain zones; (III) the neighbor-to-neighbor variant grouping manner and its effect on crack propagation; (IV) the variant selection analysis. By applying this approach, the toughness-microstructure relationship in the present case was well established, wherein the toughness is closely associated to the variant pair fractions, which is a consequence of the concrete shearing mechanism. This diversity in crystallography harnessed the crack propagation mechanism, and accordingly, introduced scattered toughness.

Track C

Theory of Formation, Growth and Movement of Argon Bubbles in Upper Nozzle of Tundish During the Argon Blowing Process

Y. Li, Z. Dong, C. Cheng, S. Wei, M. Yang, Z. Xue, Wuhan University of Science and Technology

Clogging of the tundish nozzle frequently occurs during the continuous casting of steel, which seriously disturbs the production rhythm and degrades steel quality. Generally, argon blowing in the tundish nozzle was employed in actual production to prevent nozzle clogging by means of a stable and continuous argon film on inner surface of nozzle of tundish. However, there is little research on the formation mechanism and influencing factors of the argon film of upper nozzle. The behavior characteristics of argon bubbles are studied by analyzing the balance of pressures on the bubbles in this paper. Results show that the formation, growth and movement behaviors of argon bubbles are related to argon blowing quantity, casting speed and nozzle parameters. The analytic results agree well with the results of water simulation experiments, which could provide a theoretical and technology basis to the parameter optimization of the blowing argon parameters and permeability of upper nozzle.

2:30 p.m.

Track A

Calculation of the Skull Inner Profile in the Belly Section of a Blast Furnace Based on Element Birth and Death Technology in ANSYS

R. Zhu, P. Zhou, G. Song, Q. Wen, K. Zhou, Central South University

Since the thickness and profile of the slag skull are important to reflect the working performance of the cooling stave in a blast furnace and they still cannot be detected directly under operation, a calculation model for skull profile in the belly section of a blast furnace is developed in this paper by using the Element Birth and Death technology in ANSYS. With the inner boundary condition defined by the gas flow temperature obtained from the multi-field coupling calculation of the burden, the skull profile is iteratively calculated. The results show that the thickness of the slag skull varies periodically with the arrangement of the cooper ribs. When the gas flow temperature rises as the height decreases, the slag skull shows the tendency to thin. Meanwhile, the skull is totally fused in the lower part of the belly section. So, the skull profile mainly features the structure of cooper ribs and the gas flow temperature. The model has been verified by the good consistency between the calculated temperature and the measured value at a point on the cooling stave of an operating blast furnace.

Track B

Full Field Approach for Modeling of Microstructural Evolutions During Forming Processes

P. De Micheli, S. Andrietti, N. Poulain, Transvalor Americas; L. Maire, C. Moussa, N. Bozzolo, MINES ParisTech; M. Bernacki, Transvalor Americas

A major trend in the manufacturing industry comes from the concept of "material design" to predict microstructure evolutions of metallic alloys occurring during forming processes. Regarding finite element method simulations, most of the existing models are based on classical phenomenological mean field approaches, which obviously are somehow limited. This is the reason why innovative full field approaches have been recently developed in order to enable the direct modeling of a polycrystal on a representative element volume. Therefore, various phenomena such as boundary migration, hardening, recovery, nucleation and grain growth driven by capillarity are observed and understood at the grain scale. This paper aims at demonstrating the benefits of full field finite element microstructural simulations applied to forming processes used in the field of open-die forging. Results obtained with the commercial software DIGIMU® on 304L monophasic stainless steel will be discussed.

Track C

Study of Water Droplet Behavior at Air-Water Atomized Nozzle With Acceleration Ring in Continuous Casting

C. Cheng, S. Wei, Y. Li, Y. Zhou, X. Qin, C. Zhu, Wuhan University of Science and Technology

In order to improve the uniformity of the water droplet distribution at the outlet of the cooling nozzle, an acceleration ring was used in the air passageway of the air-water atomized nozzle in the paper. A mathematical model has been established to analyze the water droplet behavior under the different process conditions. The results show that the impact strength of the air on the water flow is violent when the acceleration ring is adopted in the cooling nozzle; the mixing extent of the air and water droplet is more uniform. With the increase of backpressure of the air, the velocity of the water droplet also increases. However, with the increase of the backpressure of the cooling water, the velocity of water droplet decreases at the outlet of the cooling nozzle. The distributions of the velocity of the water droplet and the liquid volume fraction at the nozzle outlet are more uniform.

TRACK A	TRACK B	TRACK C

2:55 p.m. Refreshment Break

SESSION A4: Blast Furnace Modeling III

SESSION B4: Elemental Effects on Macrosegregation & Product Design

SESSION C4: Continuous Casting I

3:20 p.m.

Investigation of High-Rate and Pre-Heated Natural Gas Injection in the Blast Furnace✦

T. Okosun, S. Nielson, Purdue University Northwest; J. D'Alessio, M. Klaas, Stelco Lake Erie Works; S. Street, AK Steel; C. Zhou, Perdue University Northwest

With recent interest in high-rate natural gas (NG) injection in North America, it is necessary to further explore the impacts of such operation on blast furnace stability. NG avoids fines accumulation in the coke bed and has at times been cheaper than alternatives. However, high NG injection rates can lead to a quenching effect in the furnace, reducing temperatures and imposing an upper limit on the amount of gas that can be utilized. This study explores the impacts of high rates upon the blast furnace raceway, as well as the potential of pre-heated NG to alter current limitations on injection.

In-Situ 3D Experimental-Computational Analysis of the Effects of Microresidual Stresses and Microsegregation on Monotonic Loading of Ductile Iron

J. Henri, Technical University of Denmark

The understanding of the mechanisms controlling deformation and fracture of ductile iron at the microscale is still far from complete. Including key information from the manufacturing process in the analysis of the material behavior during loading can bring new insight into this complex topic. Indeed, recent synchrotron-based studies by the present authors have demonstrated that the thermal contraction mismatch between the graphite nodules and the matrix during solid-state cooling leads to localized residual elastic and plastic deformation. Furthermore, the significant Si microsegregation building up during solidification results in non-uniform properties of the matrix. In the present work, the impact of these two factors is investigated by means of in-situ tensile testing combined with digital volume correlation, serial sectioning and 3D image-based finite element modeling. The results show that accounting for these manufacturing-induced microscale phenomena is crucial to explain the mechanical behavior of ductile iron under monotonic loading.

Recent Developments in Multi-Phase/Multi-Physics CDF Simulations in Steelmaking

A. Ludwig, M. Wu, A. Kharicha, Montanuniversität Leoben

In steelmaking, the complexity of simulations that describe processes where motion of fluids is relevant has increased enormously. Non-metallic inclusions entering the mold region or depositing at the wall of the submerged-entry nozzle or equiaxed crystals that swirl around while columnar dendrites grow and interact with segregated interdendritic melt are examples of multi-phase scenarios that are currently in the focus of research. In addition, modeling of the interaction of electromagnetic fields with solidifying steel, and thus the intentional manipulation of the resulting solidification structure, are addressed more and more so that advanced aggregates in steel production can be operated more effectively. The present contribution gathers several examples of such multi-phase/multi-physics computational fluid dynamics simulations in steelmaking.

3:45 p.m.

Mathematical Simulation of Blast Furnace Operation With Natural Gas Injection

J. Tang, M. Chu, Z. Liu, Northeastern University

Blast furnace (BF) operation with natural gas (NG) injection as an effective method to reduce carbon emission and increase gas utilization efficiency has received extensive attention. In this work, the mathematical simulation of this special operation has been studied by using raceway, multi-fluid BF and exergy models. To ensure enough heat for and to keep a stable raceway, the oxygen enrichment should increase to realize thermal compensation. And as NG injection was performed, the concentration of reduction gas increased, the utilization rate of CO increased but that of H_2 decreased, and the reduction rate of burden accelerated. When NG injection was 125.4 kg/thm, the production increased 48.79%, the coke rate decreased 27.20%, and the carbon emission decreased 32.20%. Meanwhile, the thermodynamic perfection degree was improved 2.38%, while the exergy efficiency decreased 5.62%, resulting from the increasing chemical exergy of top gas.

Study on the Effect of Alloying Elements for Microstructure Control With Excellent Fire Resistance and Anti-Earthquake Performance

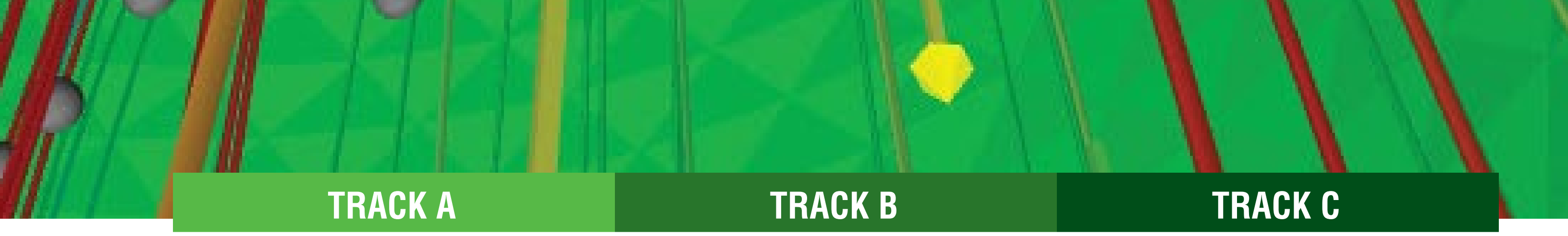
J.H. Chung, T.H. Kim, J.O. Moon, H.W. Hong, Y.D. Park, C.H. Lee, Hyundai Steel Co.

The safety design of structures in preparation for disasters such as fire and earthquake is indispensable, and the development of highly functional construction materials with fire resistance and earthquake resistance is required. However, there is no research that simultaneously exhibits fire resistance and seismic resistance. The purpose of this study is to develop structural steel with fire resistance and seismic resistance properties to withstand earthquakes and fire. Thermo-Calc and Mat-Calc were used to calculate the effect of microalloying elements which can low yield ratio and high-temperature strength. In addition, the microstructural behaviors at 600°C were analyzed in real time through the high-temperature scanning electron microscope. As a result, it can be shown that increasing the bainite volume fraction through microalloying elements replacement and cooling rate control during rolling can improve high-temperature strength.

Optimizing the Flow Conditions in the Thin-Slab Casting Mold Using Electromagnetic Brake

A. Vakhrushev, A. Kharicha, Montanuniversität Leoben; Z. Liu, Northeastern University; M. Wu, A. Ludwig, Montanuniversität Leoben; G. Nitzl, Y. Tang, G. Hackl, RHI Magnesita; J. Watzinger, Primetals Technologies

In the presented study, a magnetohydrodynamics model is developed, verified and applied to simulate the effect of the electromagnetic brake (EMBr) in regard to the turbulent flow in the thin-slab mold considering the solidification of the molten steel. A newly designed solver is presented in the current study, based on the finite-volume method and developed in the open-source computational fluid dynamics package OpenFOAM®. Both the mathematical model and the solver are verified against analytical and numerical solutions presented in the literature as well as against the laboratory measurements. After the model verification, an application of a multi-pole local EMBr configuration is optimized with regard to the magnitude and the position of the applied magnetic field. Average meniscus superheat, wall flow indexes and the evenness of the solidified shell are selected as the quantitative optimization criteria. The redistribution of the extracted heat flux under the applied electromagnetic brake is investigated. Further extension of the presented studies for the industrial application is straightforward.



TRACK A

SESSION A4 (cont'd)

4:10 p.m.

Classification of Drainage Patterns of the Blast Furnace Hearth

M. Roche, M. Helle, Åbo Akademi University; J. van der Stel, G. Louwerse, Tata Steel Research and Development; H. Saxén, Åbo Akademi University

Monitoring and control of the blast furnace hearth is critical to achieve the required production levels, adequate process operation and to extend the campaign length. Due to the complexity of the draining system, the outflows of iron and slag phases progress in different ways during tapping in large blast furnaces. To categorize the hearth draining behavior, principal component analysis was applied to an extensive set of process data from an operating blast furnace with three tapholes in order to develop an automatic classification of the outflow patterns. Representing the complex outflow patterns in low dimensions made it possible to study and illustrate the time evolution of the drainage as well as to detect differences in the performance of the tapholes. The results have also been correlated with other blast furnace variables that are known to be affected by, or affect, the state of the hearth.

4:35 p.m.

Employ Raw Material Mix and Burden Distribution Modeling to Address Cost and Environmental Challenges in Blast Furnace Operations

M. Derakhshanian, Can-Technologies Inc.

This study was conducted to investigate how software technology calculations, modeling, simulations and artificial Intelligence could be used to determine an optimum raw material mix that meet costs requirements, keeps the furnace stable and safe, and produces an acceptable quality of steel. In addition, the study investigated how to optimally distribute discharged raw materials and predict the energy efficiency of the furnace at all levels so coke consumption can be reduced while maintaining an acceptable level of production. This study showed that through on-site observation, engineering analysis, data collection, modeling and simulation using intelligent tools, the following outcomes can be achieved: An optimum raw material mix intended to reduce sinter cost while maintaining furnace stability and output quality; and a burden distribution model with on-line capability along with energy models to help BF operators to reduce furnace coke consumption with no negative consequences on production output. Therefore, it is critical for steel companies to employ the latest technologies available to run their sinter, and blast furnace operations otherwise; they will encounter difficulty competing in global market and meeting the demands placed upon them financially and environmentally.

TRACK B

SESSION B4 (cont'd)

4:10 p.m.

A Thermodynamic Database for Developing Future Stainless Steels

R. Naraghi, Thermo-Calc Software

Computational thermodynamics and kinetics utilizing the CALPHAD methodology provides guidelines for alloy/process design and optimization, and has become a powerful and flexible tool for the materials industry. It has rather early been successfully applied in the alloy development of steels and since then continuously developed toward use in more and more applications. In this presentation, the recent progress of a steel database, TCFE9, is reported. For example, descriptions of sulfides, borides, phosphates and laves phase have been improved; more importantly, the core system of the low-density steels, Fe-Mn-Al-C, has been revised. Thus, TCFE9 is very suitable for steel design with high Mn and high Al contents and it can be used for applications in automotive, cryogenic and electrical steels where low density is critical. It should also be mentioned that the work on adding rare earth elements into the database has started with Ce.

4:35 p.m.

Influence of Vanadium and Niobium Addition on Mechanical Properties in Structural Shape Steels

B.S. Koo, C.W. Lee, Y.H. Lim, Hyundai Steel Co.

A modern trend in high-rise constructions is the use of high-strength hot-rolled sections with good impact toughness. The use of higher strength enables architects to use thinner sections and allows significant reduction in the overall cost of materials. Following the trends, development of hot-rolled section steel with a minimum yield point of 460 MPa has been studied. Chemical compositions; rolling conditions, i.e., rolling temperature and speed; and quenching were carefully considered to increase strength, elongation and toughness simultaneously. Two alloying elements, niobium and vanadium, were chosen to enhance strength and impact toughness at low temperature, and rolling and quenching at recrystallization stop temperature of the precipitates were applied to maximize the austenite recrystallization-precipitation interaction during the entire hot rolling process. Mean flow stress analysis and microstructure observation have been conducted to verify the effect of precipitation hardening, along with mechanical testing for the evaluation of the material properties.

TRACK C

SESSION C4 (cont'd)

4:10 p.m.

Liquid Metal Model Experiments for Continuous Casting of Steel Under the Influence of Magnetic Fields

D. Schumann, I. Glavinic, K. Timmel, W. Willers, S. Eckert, Helmholtz-Zentrum Dresden-Rossendorf e.V. (HZDR)

Magnetic fields are widely applied in the continuous casting process to modify the flow pattern in the mold and thereby improve the quality of the semi-finished product. While the use of electromagnetic brakes (EMBr) is common in slab casting, electromagnetic stirring (EMS) is mainly applied in bloom and billet casting and recently also in slab casting. Due to the harsh conditions in the real casting process, model experiments in cold liquid metals enable accurate measurements of velocity fields, surface oscillations, gas bubble characteristics, etc. These models improve understanding of the effects of electromagnetic actuators and provide data to validate numerical models. This paper presents experimental results obtained in a model of a continuous caster, the Mini-LIMMCAST facility, where the velocity field is measured by ultrasound Doppler velocimetry. Results of experiments conducted with EMS in a round bloom geometry as well as experiments with EMBr and EMS in slab geometries are presented.

4:35 p.m.

Methods for Modeling Heat Transfer and Solidification in Continuous Casting

M. Moore, H. Ma, Purdue University Northwest; K. Morales, AK Steel Corp.; A. Silaen, C. Zhou, Purdue University Northwest

Complex flow phenomena occurring within the mold region of a continuous caster result in the natural development of unsteady oscillating flow patterns, leading to increased internal and surface defects in solidified steel slabs. These unstable flow patterns are both fundamentally challenging and expensive to recreate through plant trials. However, computational fluid dynamics modeling provides an alternative means to investigate flow instability and identify inefficiencies in current continuous casting processes. This work is part of an ongoing effort to develop a comprehensive continuous caster model, using the commercial STAR CCM+® software, and examines the simulated results obtained while performing a mesh sensitivity study for modeling the shell solidification in a continuous caster. Simulations were conducted using the k-ω shear-stress turbulence model for Eulerian-multi-phase flow of a low-carbon steel, under steady-state and transient conditions. The findings demonstrate noticeable dissimilarities in the predicted shell growth obtained using unstructured polyhedral or structured hexahedral meshing schemes for steady-state and transient simulations.

5 p.m. Reception

WEDNESDAY, 14 AUGUST 2019

TRACK A

SESSION A5: Ironmaking & Raw Materials

8 a.m.

Computational Fluid Dynamics (CFD) Modeling of Direct Reduction of Iron (DRI) Reforming Process✦

R. Liu, E. Chen, ArcelorMittal Global R&D; A. Dixon, Worcester Polytechnic Institute; C. Velazquez, ArcelorMittal Lázaro Cárdenas

To understand the complex transport phenomena during steel continuous casting, three-dimensional, high-fidelity computational fluid dynamics (CFD) models are developed to simulate transient fluid flow and microbubble motion in the caster with a curved mold design. Simulated liquid steel velocity distributions from the CFD model are verified by measurements from both full-scale water model experiment and plant trial data with a submeniscus velocity control device. Effects of submerged-entry nozzle port angle, mold width and cast speed are investigated combining both measurements and numerical simulations. A novel inclusion entrapment criterion is also developed and integrated into the CFD model to study the engulfment of particles and microbubbles into the solidifying steel shell, which is validated by slab step-milling experiments data.

8:25 a.m.

Review on Modeling and Simulation of Agglomeration in Ironmaking Process

X. Fan, X. Huang, X. Chen, M. Gan, Z. Ji, Central South University

Agglomeration is an essential process in blast furnace ironmaking, so improving its digital and intelligent production level will lay a solid foundation for smart manufacturing in the iron and steel industry. The numerical simulation model of agglomeration process is a computer-aided simulation of its physical and chemical reaction progress, which can be applied to design new technology, optimize manipulation parameters and control automatically combine with artificial intelligent algorithms. Based on reviewing the recent developments in the simulation models of sintering and pelletizing, this paper introduces the simulation models developed by a research group, and their application in optimal design of energy saving and emission reduction technologies, such as low-carbon sintering, hydrogen-rich fuel injection and flue gas circulation sintering. The needs for the further research and developments are also discussed.

TRACK B

SESSION B5: Prediction, Simulation & Detection of Cracking During Continuous Casting

8 a.m.

Simulation of Crack Initiation on the Slab in Continuous Casting Machine by FEM✦

Y. Miki, K. Toishi, JFE Steel Corp.

The critical strain for crack generation was analyzed by a high-temperature tensile test and finite element method (FEM) simulation. Based on obtained material property values, a model for crack generation by tensile strain was constructed. The local strain at the notch relative to the strain in the whole specimen was determined by a simulation of the tensile test, and the critical strain for crack generation εc was calculated. The results of a crack simulation by FEM using εc showed that the average strain until crack initiation was small under deep notch conditions. The average strain at crack generation calculated by the simulation model was in good agreement with the value measured in the tensile test. As a result of the simulation applying temperature distribution to the slab, the depth change of the oscillation mark was more influential to crack formation than the change of the width.

8:25 a.m.

Numerical Investigation of the Influence of Cooling Water Flowrate on the Generation of Cracks in Continuous Casting Molds

A.P. Storch, S. Mattedi, J.E. Pereira, ArcelorMittal Global R&D Brazil

The present study investigates the generation of cracks on the hot surface of molds for continuous casting of thick slabs. A coupled thermal/computational fluid dynamics model is used to better estimate the heat transfer coefficient of the cooling water. The heat transfer coefficient is estimated twice in the coupled model: first in normal and steady operational conditions during the casting, and then when the water flowrate is reduced due to the change of ladle. The results are input in a thermal-stress finite-element simulation in order to evaluate the fatigue generated by the thermal cycle in both hot and cold faces of the mold. The thermal-fluid-stress coupled analysis shows that the water flowrate in both conditions need to be corrected from the calculated values in the original design of the system.

TRACK C

SESSION C5: Continuous Casting II

8 a.m.

Simulation of Steelmaking Processes: An Assessment of Reducted and Full-Scale Water Modeling, Numerical Simulation, vis a vis Plant-Scale Measurements✦

D. Mazumdar, Indian Institute of Technology – Kanpur

Physical and mathematical modeling of steelmaking has been extensively applied in steelmaking process analysis and design. In physical modeling, diverse sizes of water models with different types of fluids have been popular. In contrast, computational models have been predominantly restricted to single- or at best two-phase, non-reacting fluid systems. It is often not known with certainty the extent to which predictions from such models corroborate with the actual. In this work, an assessment of physical and mathematical modeling of steelmaking with particular reference to steel processing and transfer operations is discussed. Specific examples, drawn from literature and the author's own work on ladle and tundish metallurgy, are presented. Various issues related to reduced vs. full-scale water modeling, and single- vs. multi-phase computations are examined. Results from plant-scale measurements are also presented to substantiate the discussion.

8:25 a.m.

Simulatkon Study of Tundish Heated By Plasma

M. Zhao, University of Science and Technology Beijing

	TRACK A	TRACK B	TRACK C
	SESSION A5 (cont'd)	SESSION B5 (cont'd)	SESSION C5 (cont'd)

8:50 a.m.

Track A — Static Holdup of Hot Metal and Slag in Packed Bed of Coke — A Fundamental Study

S. Ghosh, N.N. Viswanathan, N.B. Ballal, Indian Institute of Technology

Static liquid holdup in the coke bed of blast furnace determines the kinetics of important reactions, the output quality and its temperature. Hot metal is non-wetting to coke, whereas wetting characteristics of the slag varies due to exchange reactions between slag, metal and coke. The potential site for static liquid holdup largely is at the two sphere contacts in the packed bed. This work tries to determine the stability of liquid film between two touching vertical coke spheres by a total energy minimization method. Estimates are made of the maximum holdup of hot metal and slag for various contact angles. It is found that hot metal has low stability in between coke particles, whereas larger volume of slag is stable. In high-temperature experiments, hot metal mostly stays covered by the slag. This result matches with the observation of the simulation in this work. This has useful implication in predicting the reaction kinetics.

Track B — Investigation of Flow and Solidification Continuously Cast Blooms With Chamfering Mold

H. Zhang, Q. Fang, H. Ni, C. Liu, Wuhan University of Science and Technology

A chamfering mold technology has been brought forward to remove the transverse corner crack of 380 mm × 280 mm bloom poured by diagonally installed four-port submerged-entry nozzle. In order to determine a proper chamfer dimension for the bloom, the effects of chamfer dimensions on flow pattern, heat transfer and initial solidification behavior in the mold zone were investigated. The results showed that the chamfered mold can avoid the retention of molten steel at the mold corner and apparently enhance the corner temperature. As the chamfer dimension increases, the mobility of liquid steel and corner temperature increases as well, while the growth velocity of the solidifying shell at the corner reduces. The proper chamfer dimension for 380 mm × 280 mm bloom is around 10–15 mm, by which the corner temperature of bloom casting can be increased to avoid the brittle temperature, a reasonable growth pattern of solidifying shell can be guaranteed, and the crack occurring probability can be reduced.

Track C — Modeling Tundish Heat Loss Under Different Slag Behaviors With Gas Bubbling

S. Chang, Z. Zou, B. Li, L. Zhong, Northeastern University; R. Guthrie, McGill Metals Processing Centre

During deep cleaning of liquid steel in a tundish using gas bubbling, a "slag eye" usually appears due to the impact of resurfacing bubbles, leading to reoxidation and heat loss of the liquid steel. Water modeling was carried out in a full-scale, 4-strand tundish, in order to control the formation of the slag eye during gas injection by refining the size of bubbles. A novel ladle shroud with tiny orifices on the top was used to produce micro-bubbles, as small as 0.54 mm in diameter. The corresponding numerical model was established to estimate the tundish heat loss under different slag behaviors, considering the convection and radiation heat transfer of a slag eye. The result showed that the diameter of "slag eye" reduced from 280 mm to 0 mm, with decreasing bubble sizes from 2.53 mm to 1.41 mm, which reduced the heat loss of the entire tundish surface by 17.35%.

9:15 a.m.

Track A — Modeling of Continuous Scrap Pre-Heating

C. Schubert, M. Eickhoff, H. Pfeifer, RWTH Aachen University

To predict the efficiency of the pre-heating process and prevent overheating and partial melting of the scrap, numerical simulations are a helpful tool for dimensioning. Scrap is typically modeled as porous media with the hot offgas flowing through it. In the case of a continuous pre-heating system, the scrap moves through the reactor while it is heated up by the offgas counterflow. In all known computational fluid dynamics solvers, the porous media consists of a solid zone and fluid zone at the same location. To implement the convection of the scrap, a second fluid zone with a defined velocity is set up. Source terms calculated in user-defined functions manage the correct temperature distributions of the zones. Additionally, this kind of configuration offers the possibility to implement radiation along with the porous media, which is not possible with the given setting options of, for example, ANSYS Fluent.

Track B — Study on Numerical Simulation Strategy for Spray Cooling During Continuous Casting Process

H. Ma, A. Silaen, C. Zhou, Purdue University Northwest

In the continuous casting secondary cooling process, heat is extracted from the slab surface by cooling water sprayed from an array of nozzles. Efficient and uniform heat removal without cracking or deforming the slab is desired. The current study presents a numerical spray cooling model featuring the simulation of atomization and droplet impingement heat transfer during secondary cooling. Parametric studies are performed to investigate the effects of spray angle and the nozzle arrangements on heat transfer coefficient, and the relationship between casting speed and water flowrate. The simulation results provide insight into the optimization of secondary cooling practices under different conditions.

Track C — CFD Optimization Tools Applied to Tundish Refractory Design

A. Dolabella Resende, R. Alves Freire, P. Shivaram, G. Hackl, RHI Magnesita

Tundish refractory design significantly influences the flow pattern in the vessel, providing the necessary conditions for clean steel production. In order to obtain desirable flow patterns, some commonly used furniture are impact pots, weirs and dams. Nevertheless, for these refractory components to provide the maximum benefit for operation, it is essential that their design is optimum for the specific tundish in consideration. In this study, the application of numerical optimization tools in the tundish refractory design is presented. The optimizations are based on the results of computational fluid dynamics numerical simulations, which feed adaptive optimization algorithms based in response surface generation. Through this approach, it is possible to design the tundish refractories in order to obtain optimum operational conditions such as: maximum steel residence time, minimum refractory wear and minimum turbulence at the slag interface.

9:40 a.m. Refreshment Break

TRACK A	TRACK B	TRACK C
SESSION A6: Weldability & Fracture Toughness	**SESSION B6: Oxygen Steelmaking**	**SESSION C6: Continuous Casting III**

10:20 a.m.

TRACK A — SESSION A6: Weldability & Fracture Toughness

Quantitative Relationship Between Fracture Toughness and Crystallographic Structure in High-Strength Steel: Visualized and Digitized Characterization of Bainitic or Martenitic Misrostructure

C. Shang, University of Science and Technology Beijing

The aim of this paper is to carry out a study on crystallography of coherent transformation products for high-performance steel, and to explore the qualitative and quantitative relationship between crystallographic structure and low-temperature fracture toughness. Several breakthroughs have been made in the following aspects: (1) New methods to extract a large database of crystallographic information to screens, and visualized and digitized characterization of crystallographic structures of low-alloyed, high-strength steel were developed. The reconstruction of prior austenite grain was realized by using MATLAB according to the coherent transformation relationship, i.e., orientation relationship (OR) between mother austenite and daughter transformed products. Moreover, the quantitative characterization of bainitc variant, variant pairs and the density of high-angle boundary can be completed by using euler angle (ϕ1, Φ, ϕ2) of the scanning pixels and the actual OR. (2) A direct correlation between crystallographic structure and fracture toughness has been established. By reconstructing the austenite and calculating the austenitic orientation and crystallographic orientation relationship, (a) the quantitative relationship between crystallographic structure obtained in coherent transformation process in welding coarse-grained heat-affected zone and impact toughness was found, (b) the rule of variant selection influenced by austenitizing temperature in quenching process (austenite grain size effect) was studied, and (c) its effect on the density of grain boundary (block, sub-block and packet) and low-temperature toughness was investigated. (3) The above new method and theory are gradually used into the field of investigation on offshore engineering steel and construction steel.

TRACK B — SESSION B6: Oxygen Steelmaking

Design of a New BOF Oxygen Lance Using CFD Simulation

A. Storch, H. Silva Furtado, A. Alves Bernabe, R. Sartim, ArcelorMittal Global R&D Brazil

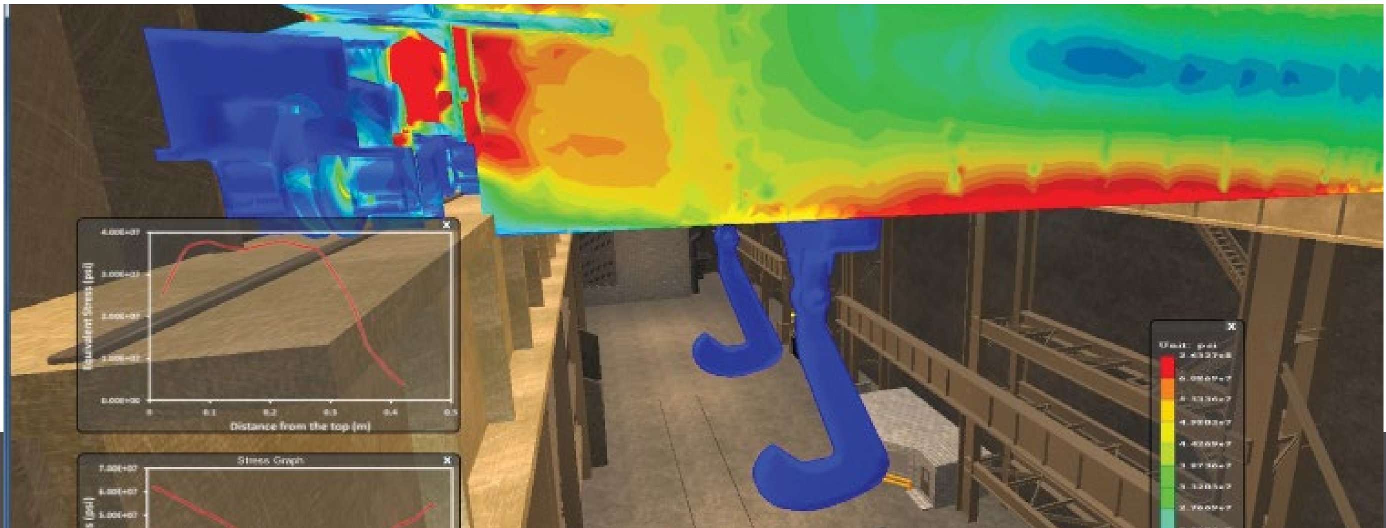
The vessel design and operational parameters in every steelmaking shop around the world are unique. In the present study, the oxygen lance design for the basic oxygen furnace (BOF) converters in ArcelorMittal Tubarão is optimized and tested entirely using numerical simulation. First, the design of the supersonic nozzles is adjusted by using the compressible flow theory along with a numerical simulation of the supersonic oxygen jet on ANSYS Fluent. Then, a conjugate heat transfer simulation is done in order to compare the cooling performance of the new lance to the existing model. Finally, the compressible oxygen jet interaction with the molten bath is simulated in a three-phase computational fluid dynamics (CFD) simulation, where the performance of the two lances is compared in terms of jet length and mixing time. The results show the advantage of CFD when evaluating processes that would not be possible to physically measure, such as the harsh conditions inside a BOF converter.

TRACK C — SESSION C6: Continuous Casting III

Modeling of Transient Behavior of Top-Surface Slag/Molten Steel Interface in Continuous Slab Casting✦

S. Cho, B. Thomas, Colorado School of Mines

The liquid slag layer that floats on the molten steel pool near the mold top during continuous casting helps to prevent oxidation of the molten steel, remove non-metallic inclusions and lubricate the solidifying steel shell against the oscillating mold. However, abnormal or instable surface flows due to non-optimal casting conditions can cause slag entrainment into the molten steel and later entrapment into the steel shell, resulting in surface and/or internal defects in the final products. This work applies large eddy simulations coupled with the volume of fluid method to simulate transient molten steel flow, liquid slag/molten steel interface motion, and slag behavior in a typical slab mold during nominally steady casting. The model has been validated with plant measurements and reveals the relation between jet wobbling, surface-level fluctuations and potential slag entrapment defects via sudden level drops near the meniscus.



	TRACK A	TRACK B	TRACK C
	SESSION A6 (cont'd)	**SESSION B6 (cont'd)**	**SESSION C6 (cont'd)**
10:45 a.m.	Effect of Ca, Mg and Ti Additions on the Microstructures of Offshore Steels for High-Heat-Input Welding *X. Ma, Y. Sun, P. Zhang, The University of Queensland; H. Liu, HBIS Group Co. Ltd.; Z. Rong, G. Wang, B. Zhao, University of Queensland* To improve the strength and toughness of the heat-affected zone of high-heat-input welding steels, the concept of "oxide metallurgy" has been proposed to address the issue by utilizing inclusions and precipitates. However, the mechanism of using strong deoxidants has not been fully understood. In this study, the deoxidation of using Ca, Mg and Ti was calculated by FactSage for the inclusion stability of Fe-Al-Ti-O, Fe-Ti-Mg-O and Fe-Ti-Ca-O systems. Deoxidation of synthetic steels by strong deoxidants were experimentally simulated in lab. The results showed that the grain size of prior austenite at 1,673 K significantly decreased with Ca and Mg addition. The inclusions and precipitates were characterized by scanning electron microscopy, electron probe microanalyzer and transmission electron microscopy to clarify the mechanism of microstructure improvement with Ti-, Ca- and Mg-containing particles.	Some Aspects of CFD Converter Modeling Performed in Recent Decades *M. Ersson, A. Tilliander, N. Andersson, KTH Royal Institute of Technology* Computational fluid dynamics has emerged as a useful tool in metallurgical processes in which experimental measurements are very difficult and costly. Consequently, there has been a sizable effort in modeling these systems to reduce costs and to increase fundamental knowledge. The conclusion that can be drawn is that many models have investigated particular areas of the converter process, but no model has managed to take into account all relevant aspects, including phenomena such as supersonic, high-temperature, multi-phase and reacting flows. The continued development toward such models will provide answers where empirical and analytical models need additional input.	Using a Numerical Model to Study the Transient Clogging Phenomena in SEN During Continuous Casting of Steel *M. Wu, H. Barati, A. Kharicha, A. Ludwig, Montanuniversität Leoben* A model for the clogging of submerged-entry nozzle (SEN) during continuous casting has been proposed by the authors. The following phenomena of clogging were considered: transport of the non-metallic inclusions (NMIs) as particles in the turbulent flow of steel melt; deposition of the NMIs and buildup of the initial layers of clog on the SEN wall; continuous growth of clog region (as porous medium) due to further deposition of NMIs; the interaction of the clog region with the melt flow; and possible solidification of steel melt in the porous clog region. This contribution explains the clogging-related phenomena during operation of continuous casting of steel by using the numerical model. The final goals of this study are to further evaluate the numerical model and to achieve deeper understanding of the SEN clogging. Due to the limitation of the computer hardware, the calculation domain had to be limited in a small part of the tundish and in the SEN, and the number of NMIs reduced by introducing a so-called N-factor to speed up the calculation. These simplifications might prevent the modeling results from being applicable for the quantitative prediction of clogging process, but the modeling results provide valuable qualitative information about the correlation of the aforementioned clogging-related phenomena with the process parameters.
11:10 a.m.	A CFD Model for Electron Beam Welding of CrMnNi Steels *S. Borrmann, R. Schwarze, TU Bergakademie Freiberg* In terms of industrial applications of new materials, such as the investigated CrMnNi steels, fusion welding is an essential process. In this context, electron beam welding (EBW) has shown excellent weldability. In order to support and reduce experimental efforts for the investigation of influences of process and material parameters on the welding seems, numerical models can be consulted. Therefore, a computational fluid dynamics model regarding EBW is developed and implemented into OpenFOAM. The model considers the underlying phase change processes, heat transfer and fluid flow in the melt pool. The heat input of the electron beam into the steel is modeled with a complex heat source. The particular temperature-sensitive steel properties are taken into account. The numerical results are validated with experiments with defined parameters and weld geometries. The presented model aims to be a basis for implementing additional extensions to lay the ground for further applications.	Importance of Emulsion Zone in Oxygen Steelmaking *A. Kadrolkar, N. Dogan, McMaster University* Developing a comprehensive model for top-blown oxygen steelmaking that incorporates and critically investigates the refining reaction kinetics is the focus of a study by the authors of this paper. The central thesis of the model is that the kinetics of oxygen steelmaking is dominated by changes in the behavior of iron droplets in the emulsion during the main blow, in particular, in the early part of the blow when the droplets generated from the impact region "bloat" and remain in the emulsion for relatively long periods. This paper will discuss decarburization reaction kinetics and mechanisms by incorporating internal and external CO gas generation as well as its escape rate from a single droplet under various operating conditions in oxygen steelmaking. In this paper, the evidence for the theory will be critically examined and repercussions of the new theory to plant design and operation will be discussed.	Development of a Combined Fluid Flow, Solidification and Particle Dynamics Model in OpenFOAM for Prediction of Particle Entrapment in Continuous Casting Slabs✦ *A. Kannan Iyengar, T. Bhattacharya, ArcelorMittal Global R&D* Extensive research and plant observation have shown that particle-related defects associated with fluid flow in the tundish and continuous casting mold are responsible for most of the serious defects in final rolled steel products (e.g., in automotive or plate/pipe products). Once delivered into the mold from the tundish, steelmaking inclusions could become entrapped in the solidifying slab to form defects. This paper describes the development of a combined fluid flow, solidification and particle dynamics model using the OpenFOAM framework for the prediction of particle-related defects inside a continuous casting mold. The current work will also shed some light on how to bridge the gap of bringing high-fidelity simulation results from higher-order physics-based models to the shop floor for real-time defect prediction via creation of reduced-order models with the application of advanced machine learning and artificial intelligence techniques.

TRACK A	TRACK B	TRACK C
SESSION A6 (cont'd)	SESSION B6 (cont'd)	SESSION C6 (cont'd)

11:35 a.m.

TRACK A — SESSION A6 (cont'd)

Investigation on the Weldability of High-Strength Steels Used for Low-Temperature Environment

C. Shang, Z. Xie, Z. Wang, University of Science and Technology Beijing; S.V. Subramanian, McMaster University

With the development of modern high-strength steels, the application fields have gradually transferred to low-temperature environments, such as deep sea or Arctic regions. Therefore, weldability has become a new challenge, especially low-temperature toughness. To satisfy the requirement of welding engineering in the low-temperature environment, the composition design of welding wire and optimization of welding parameters usually are regarded as highest-priority considerations. Moreover, for some special weldments, such as hot-bending pipe and heavy elbow, heat treatment will be used after welding, and thus it also will become one of the most crucial steps. Therefore, a series of experiments from the development of welding wire to double-sided submerged-arc welding for pipeline steel, multi-pass welding for offshore engineering steel and post-weld heat treatment for multi-pass welded heavy elbow are completed in the present study. The results indicated that the optimization of alloying elements (Mn/Ni/Mo) in welding wire and welding parameters could ensure the ductile to brittle transition temperature of weld metal lower than –60°C. Moreover, ~130°C interpass temperature is more suitable for multi-pass welding of offshore engineering steel. Although it was easy to form some brittle reheated zones in multi-pass weld metal, it was found that there is an insignificant effect on toughness through conventional tempering — an obvious improvement through the combination of quenching plus intercritical annealing and tempering as formation of ~6 vol.% retained austenite and decomposition of M/A constituents — and it is practically viable in an industrial scale.

TRACK B — SESSION B6 (cont'd)

Dynamic Optimization of Basic Oxygen Furnace Operation

D. Dering de Lima Silva, C. Swartz, N. Dogan, McMaster University

This study aims to develop an optimization routine for the basic oxygen furnace (BOF) that provides operators with the optimal combination of input trajectories and process conditions that minimizes operating costs while meeting the targeted endpoint carbon content and temperature. The lance height and oxygen flowrate were selected as optimization variables and their potential effects on meeting the desired endpoint carbon content were studied. Preliminary results show how the oxygen flowrate and lance height should vary with time to minimize the oxygen usage, while meeting a desired endpoint carbon content. Further constraints can be added to guarantee that the temperature of the raw steel produced is within the desired specifications. This paper will present the first principles dynamic BOF model used, the optimization framework and results from initial optimization case studies. Impacts of the model application to plant operations will be discussed.

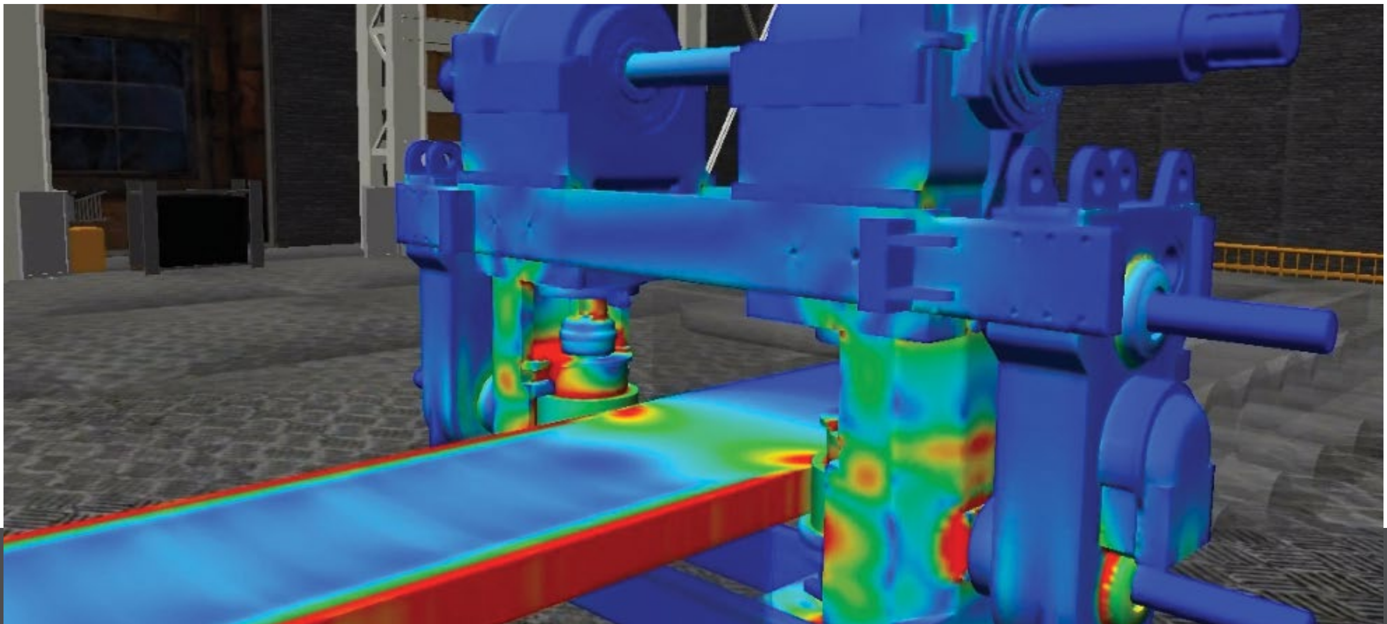
TRACK C — SESSION C6 (cont'd)

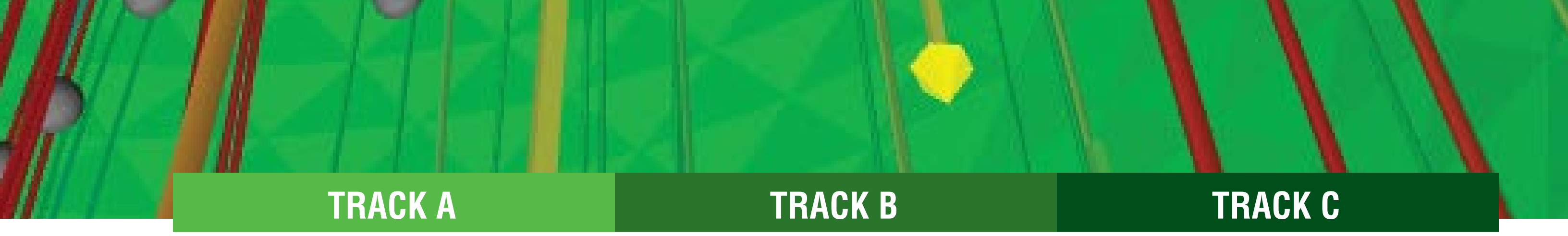
Simulation of Inclusion Properties by Means of a Reduced Two-Dimensional Population Balance Model

A. Dutta, B. Blanpain, KU Leuven

Non-metallic inclusions (NMIs) play a key role in steelmaking research to develop the so-called oxide metallurgy technology, influencing both processing and application of steel products. To control the characteristics of inclusion population in liquid steel, several variables such as number density, composition, morphology and spatial distribution are necessary. A typical modeling approach, considering two-dimensional growth and nucleation, would lead to a high-dimensional population balance model, which brings considerable complexity in solution accuracy and computational time. A simple yet accurate approach is to perform model reduction in which the model is first transformed into another coordinate system. The two new coordinates are inclusion volume and inclusion shape factor. Under certain assumptions, the reduced model leads to a system of only a few coupled population balance equations, which preserves the averaged habit and dispersity information of the NMI crystals.

Noon Lunch





TRACK A	TRACK B	TRACK C
SESSION A7: Steel-Slag Interaction	SESSION B7: Ladle Metallurgy Mixing I	SESSION C7: Continuous Casting IV

1 p.m.

Track A — Investigation of the Effects of Bubble Initial Diameter and Gas Flowrate on the Slag Eye Size in a Steel Ladle With Bottom Plug

J. Vandenoever, N. Walla, A. Silaen, Purdue University Northwest; A. Voss, H. Oltmann, A. Pitts-Baggett, E. Pretorius, Nucor Steel; C. Zhou, Purdue University Northwest

Stirring of liquid metal with inert gas through stir plugs in the bottom of the ladle is widely implemented at ladle treatment stations. To ensure high-quality steel is produced, a range of stirring conditions from hard stirring for mixing and sulfur removal, to gentle stirring for inclusion removal is required. In this paper, an iso-thermal and unsteady three-dimensional computational fluid dynamics (CFD) technique is used to study the flow pattern inside the ladle and the slag eye size in order to optimize the mixing conditions. Multi-phase flow characteristics are simulated using the volume of fluid (VOF)-Lagrangian method, where the VOF method is used to track the liquid steel and liquid slag and the Lagrangian method is used to track the argon bubbles. The effects of bubble initial diameter and gas flowrates on the flow characteristics have also been investigated. When comparing the slag eye size obtained in real plant conditions with CFD simulation, good agreement has been observed.

Track B — The Influence of Different Turbulence Models on the Fluid Flow Characteristics in Gas-Stirred Ladles✦

Q. Cao, L. Nastac, University of Alabama

A three-dimensional discrete phase model-volume of fluid (DPM-VOF) coupled model was developed to study the argon/steel/slag/air multi-phase turbulent flow in the industrial gas-stirred ladle. In addition, the coalescence, expansion and breakup of the argon bubbles as well as the fluctuant slag layer were taken into account in the model. The model was validated by comparing the simulated results of the fluid flow with the experimental data in a water model reported in the literature. Then, the influence of different turbulence models on the simulated flow characteristics in the ladle was investigated in detail. The modeling results show that the choice of the turbulence model has a significant impact on the predicted multi-phase turbulent flow characteristics in the studied industrial gas-stirred ladle.

Track C — Numerical and Experimental Studies on Fluid Flow and Microbubble Entrapment During Continuous Casting With a Curved Mold Design✦

R. Liu, ArcelorMittal Global R&D; R. Zhou, Purdue University; H. Yin, B. Forman, R, Moravec, ArcelorMittal Global R&D

To understand the complex transport phenomena during steel continuous casting, three-dimensional, high-fidelity computational fluid dynamics (CFD) models are developed to simulate transient fluid flow and microbubble motion in the caster with a curved mold design. Simulated liquid steel velocity distributions from the CFD model are verified by measurements from both full-scale water model experiment and plant trial data with a submeniscus velocity control device. Effects of submerged-entry nozzle port angle, mold width and cast speed are investigated combining both measurements and numerical simulations. A novel inclusion entrapment criterion is also developed and integrated into the CFD model to study the engulfment of particles and microbubbles into the solidifying steel shell, which is validated by slab step-milling experiments data.

1:25 p.m.

Track A — Interface-Resolved Simulations of Transient Behavior of the Slag Eye and Entrainment of Slag Droplets

Q. Li, Northeastern University; P.C. Pistorius, Carnegie Mellon University

Detailed knowledge of the slag eye zone is crucial for the improvement of refining performance and inclusion cleanliness in the industrial practice of gas-stirred ladles. Despite many reported studies, the understanding of even some fundamental steps like the entrapping mechanism of slag-based inclusions is limited. This study presents an interface-resolved model that has the resolution to directly simulate bubbles and droplets. This model is applied to the study of a 150-ton industrial ladle furnace under steelmaking conditions to investigate the primary phenomena of bubble-droplet-metal-slag interactions. In particular, transient features of the slag eye and the mechanism of slag droplets entrainment were analyzed, as was the effect of gas flowrate. It is concluded that a higher flowrate will introduce more transient behavior, as well as a higher risk of slag-based inclusions.

Track B — Study of Mass Transfer and Influence of Mixing Using a Computationally Efficient 3D Numerical Model of a Gas-Stirred Ladle

D. Abreu-López, M. Ramírez-Argáez, Universidad Nacional Autónoma de México; B. Blanpain, A. Dutta, KU Leuven

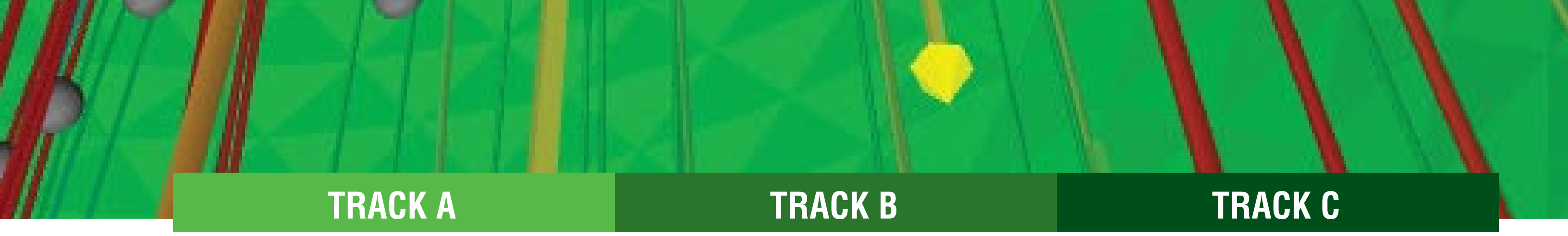
Secondary refining is an integral part of steelmaking in which gas-stirred ladles play an important role in the production of high-quality steel. In this study, a three-dimensional, three-phase model of a steel ladle has been developed using computational fluid dynamics. The model involves liquid-liquid mass transfer using a semi-empirical approach. The 3D model is validated for flow and turbulence using available experimental data, valid for both centric and acentric gas injections using a scaled (1:7) water-oil physical model. Using a computationally efficient approach, the time needed to achieve convergence in pseudo-steady state has been reduced to few hours using an Intel Core i7 processor (8M Cache, 3.40 GHz). Finally, the mixing time has been compared with the previously established 2D simulations to investigate model improvement due to the addition of third dimension in a cylindrical coordinate system.

Track C — Modeling of Bubble Behaviors in a Slab Continuous Casting Strand Using Multiple Size Group Approach

H. Zhou, L. Zhang, University of Science and Technology Beijing

The behavior of bubble coalescence and breakup affects the flow pattern in the mold directly. In the current study, a water model experiment was employed to validate the mathematical model in terms of the distribution and size of bubbles. Then, the gas volume fraction, bubble coalescence and breakup, and bubble size distribution were investigated in a slab continuous casting strand using the Eulerian–Eulerian and multiple-size-group approach. The complex interfacial momentum transfers between the two phases are considered. The results show that the bubble diameter increases with increasing gas flowrate and decreases with casting speed. From the submerged-entry nozzle to the narrow wall, the distribution of bubble diameter shows a rising tendency before decline. In addition, an optimal gas volume fraction was defined to maintain double roll in the mold.

	TRACK A	TRACK B	TRACK C
	SESSION A7 (cont'd)	**SESSION B7 (cont'd)**	**SESSION C7 (cont'd)**
1:50 p.m.	Effect of Slag Composition on the Formation of $MgO \cdot Al_2O_3$ Spinel Inclusions During Ladle Treatment Using a Coupled Reaction Model *J.-I. Kim, S.-J. Kim, Chosun University; S. Kitamura, IMRAM Tohoku University* $MgAlO_4$ spinel inclusions ("Mg-Al inclusion") are harmful to the properties of steel products. There are many efforts to control the composition of harmful inclusions during ladle treatment, where the complex reactions among molten steel, slag, refractory, deoxidation products and alloying elements occur simultaneously. It is well known that the pure Al_2O_3 inclusion was changed to Mg-Al inclusion because of the reaction with Mg content in molten steel. In the present work, in order to predict inclusion evolution from Al_2O_3 inclusion to Mg-Al inclusion, a kinetic model was introduced that applied Mg content changes in spinel. By the brushed-up model, the influence of slag composition and CaF_2 contents on the behaviors of Mg-Al inclusion were investigated. Also, slag basicity to suppress the formation of Mg-Al inclusions will be discussed.	CFD Modeling and Pilot-Scale Validation of Argon Purging in Steel Ladles *K. Subramanian, E. Harbers, Tata Steel Europe; A. Richardson, Material Processing Institute; D. van der Plas, Tata Steel Europe* A three-dimensional computational fluid dynamics model using an Euler-Lagrangian approach is developed in order to understand the mixing of liquid steel in a ladle using argon-purging plugs in the bottom. The simulations consider liquid steel and slag as continuous liquid phase and argon as particles. Experiments were performed in a pilot-scale 7-ton ladle to view the slag eye formation. The simulation results were validated using the dimension and position of the slag eye for different flowrates and slag thickness. The results are also compared against an empirical equation available in the literature.	Physical Simulation and State-of-the-Art Visualization of Complex Continuous Casting Flows Using a Full-Scale Water Model System *B. Konar, D. Li, K. Chattopadhyay, University of Toronto* A state-of-the-art, full-scale experimental physical model of the continuous caster mold (CC model) has been commissioned at the University of Toronto's Process Metallurgy Research Labs to investigate complex multi-phase liquid steel flows. The CC model comprises a full-scale water model mold, reduced-scale water reservoir representing the tundish, and is fitted with an interchangeable industrial stopper rod and industrial slidegate system. The full-scale physical model is heavily instrumented using high-speed cameras, high-definition video cameras, flex grid particle image velocimetry, and anemometers to enable in-situ flow visualization and quantification. In the CC model, full-scale industrial submerged-entry nozzles (SENs) can be tested prior to performing cost- and time-intensive plant trials. Additionally, new SEN designs can be evaluated by 3D printing plastic SENs on-site and testing them rapidly. The CC mold serves as a physical replica to optimize the variables (the casting parameters and SEN design parameters). The design of the CC model along with the flow quantification tools will be presented. Several experimental case studies of flow visualization correlating the flow fields with the casting variables will be discussed.
2:15 p.m.	Modeling of Inclusion Motion Across Steel-Slag Interface *W. Liu, S. Yang, J. Li, F. Wang, University of Science and Technology Beijing* Most inclusions are removed by slag absorption. The transferring motion of the particle inclusions at the molten steel–liquid slag interface is very important for the optimization of steel cleanness. A mathematical dynamic model based on force analysis was built to simulate the floating in steel, crossing interface and dissolving in slag of inclusion. A wide range of Reynolds numbers were adapted for inclusion. The model was validated using a physical model and was used to study the influence of interfacial characteristics on inclusion removal. Some advice on improving inclusion removal from steel by interface and slag absorption will be given. The interaction between inclusion dissolution and motion will also be discussed.	Validation Techniques to Determine the State of Accuracy of Numerical Multi-Phase Modeling *T. Haas, M. Eickhoff, H. Pfeifer, RWTH Aachen University* Numerical models involving multi-phase flows are still considered vague by numerous plant operators. To increase the confidence in those models, a detailed validation procedure is crucial. Therefore, different validation techniques, namely particle image velocimetry for flow measurements, convolutional neural networks for bubble swarm tracking and conventional image processing for slag eye formation, are presented in this work. Their advantages and challenges are discussed. Finally, a numerical model for the ladle is introduced and its results are compared to the validation data. By that, the accuracy of current submodels will be determined and potential improvements will be discussed.	Numerical Modeling of the Flow Field in a Bloom Caster Under the Influence of an In-Mold Electromagnetic Stirrer *S. Kesavan , P. Ramirez Lopez, H. Yang, P. Jalali, R. Safavi Nick, SWERIM AB; X. Pereda, SIDENOR I&D* The increase on the global demand of steel requires a rise in productivity that can be achieved through faster casting speeds. However, higher velocities affect process stability and product quality due to the increased mass flowrate in the caster. Electromagnetic stirring (EMS) has been introduced as an alternative to control the metal flow in the mold in modern casters. The present study investigates the implementation of EMS during bloom casting with the aid of numerical modeling. The research explores the limitations and challenges for implementation of electromagnetic stirring during solidification, including the multi-phase flow of steel-slag and mold oscillation during casting. Particularly, the study focuses on the flow pattern at the meniscus and within the mold in order to understand the underlying relationship between flow and phenomena and solidification on different mold regions.
2:40 p.m.	Refreshment Break		



TRACK A

SESSION A8: Material Handling & Tracking

3:15 p.m.

Burns Harbor Hot Strip Mill Shipping Simulation: Optimized Material Handling Using FlexSim Simulation Software

J. White, T. Preall, ArcelorMittal Burns Harbor; M. Nikoo, Purdue University

On-time delivery of product to customers is an important performance metric for maintaining positive customer relationships, ensuring continued business and maintaining competitiveness. At ArcelorMittal Burns Harbor, a project was developed to improve the flow of finished hot band product through the hot strip mill shipping bays. A FlexSim model was used to map the product flow through the shipping warehouses and update the inventory in each bay. The model was fine-tuned by benchmarking against historical data to arrive at similar inventory levels as actual production. Improvement strategies were tested using scenario analysis, changing flowrates, increasing capacities and changing base assumptions. The model analyzed truck on-site time, crane and truck dock utilization, coil throughput and maximum trucks per hour ship rate through the facility. Results from the shipping model identified bottlenecks within the current process flow, highlighted underutilized assets and paved the way for potential improvement strategies.

3:40 p.m.

Modeling of Pilemaking Process Using On-Time Process Data

G. Saran, A. Ganguly, Tata Steel Ltd.

Pilemaking is a phenomenon in which material is stacked horizontally on top of each other in layers. The layers are few hundred meters long, comprise 100 KT of material prepared over a five- to seven-day period and consist of approximately 400 layers. In an effort to create proper visibility of the above process, a 2D/3D pile profile has been generated over the pile-making period by utilizing the on-line process parameters of material stacking tonnage and position of stacking of the same. The on-line tonnage is captured from the belt of the stacker machine and the position where it discharges the material is captured from the encoder fixed near the wheel of the stacker machine. The pile model facilitates operations in mining and beneficiation area of Tata Steel to adjust the process of pilemaking in an effort to attain homogeneity of the pile quality. This helps in reducing the standard deviation of the raw material mix when it is dispatched to sinter-making plants of Tata Steel Jamshedpur.

TRACK B

SESSION B8: Ladle Metallurgy Mixing II

3:15 p.m.

Simulation of the Heat Transfer Within the Ladle Furnace

A. Reimann, T. Hay, T. Echterhof, H. Pfeifer, RWTH Aachen University

A model for radiative heat exchange in a ladle furnace was developed to evaluate the influence of different furnace geometries and operation strategies on refractory and electrode wear. The freeboard wall surface is divided into several elements to calculate the varying thermal loads around the circumference of the ladle. Both the freeboard and electrodes are divided into sections along the vertical as well and view factors are calculated for each surface within the furnace based on a simplified CAD model. The melt surface is sectioned as well to account for the melt being partially covered by slag and the ladle wall is divided into layers for the different types of refractory and the outside steel layer, making up the wall and bottom of the ladle. The resulting equations are solved using matrix operations in Matlab, allowing for efficient calculation with a variable number of surface elements.

3:40 p.m.

Investigation of a Novel Horizontal Induction Stirring in the Ladle Process

R. Safavi Nick, SWERIM AB; L. Teng, H. Yang ABB AB/Metallurgy; J. Björkvall, J. Alexis, SWERIM AB

Ladle induction stirring has existed for decades. Traditional induction stirring creates one vertical rotation of the whole melt in the ladle. This paper investigates the effect of one horizontal induction stirring on the refining process. The present study models horizontal induction stirring and its effects on the flow pattern of the liquid bath. The result shows that horizontal stirring eliminates the formation of the open eye and at the same time maintains a high level of stirring energy in the melt. Horizontal induction stirring reduces the risk of slag entrapment and increases the residence time of inclusions at the steel-slag interface. The effect of the positions of the induction stirrer at different melt heights and the effects on the flow pattern have also been investigated.

TRACK C

SESSION C8: Continuous Casting V

3:15 p.m.

The Influence of Thermo-Physical Properties on Slag Entrainment During Continuous Casting of Steel in Billets and Slabs

H. Yang, S. Kesavan, SWERIM AB, D. Mier Vasallo, SIDENOR I+D; M. Cornille, ArcelorMittal Maizières; P. Ramirez Lopez, SWERIM AB

Entrainment occurring due to detachment of slag at the metal-slag interface is a major source of inclusions in final as-cast products. This occurs due to instabilities at the interface caused by local flows resulting in slag entrainment through several mechanisms. In this study, the influence of material properties such as viscosity, density, surface tension and interfacial tension on slag entrainment are studied numerically. Additionally, models for estimating slag properties are investigated and compared to actual measurement data. These properties were used on detailed models for reference cases and challenging steel grades for casting of case hardening and microalloyed steel billets (185 x 185 mm) under electromagnetic stirring (EMS), as well as low-alloyed grades slabs produced in a pilot slab caster (450 mm x 100 mm). As a result, changes in slag properties can be suggested to minimize slag entrainment during continuous casting.

3:40 p.m.

Analyzing of Non-Sinusoidal Mold Oscillation Modes in Continuous Casting of Steel Through Advanced Numerical Modeling

P. Jalali, SWERIM AB

An advanced numerical model, developed by SWERIM AB, has been used to study the effect of different casting parameters on the process stability for a peritectic steel grade in a Scandinavian steel producer. The model is based on commercial code ANSYS Fluent, which solves the Navier-Stokes equations by use of an interface tracking technique known as volume of fluid for a multiple-phase system of steel and slag. As a result, it predicts metal flow and slag infiltration as well as their influence on heat flux and solidification under transient conditions and different mold oscillation settings.

	TRACK A	TRACK B	TRACK C
	SESSION A8 (cont'd)	**SESSION B8 (cont'd)**	**SESSION C8 (cont'd)**
4:05 p.m.	**Modeling Approach of the Slab Handling Between Casting and Hot Rolling** *A.J.C. Burghardt, Tata Steel Research & Development* At Tata Steel Europe in IJmuiden, cast slabs are handled in different ways on their route to the reheating furnace of the hot strip mill. To avoid failure, rules are followed that prescribe maximum storage times and minimum entrance temperatures. Obviously, the strictest rules hold for slabs of steel grades that are known to be sensitive to clinking. However, most prescriptions are still based on experience and have the status of rules of thumb. Within Tata Steel Research & Development, thermomechanical models are now being used to simulate the process route of slabs from the moment of casting up to and including reheating. The simulations enable the various influences on clinking sensitivity to be mapped out, the latter being characterized by a so-called minimum critical crack length. With this knowledge, more adequate process routes can be pursued in the light of safety and cost efficiency.	**An Assessment of Numerical Approaches Toward Multi-Phase Hydrodynamic Modeling of Inert Gas-Stirred Ladle Systems** *R. Mishra, D. Mazumdar, Indian Institute of Technology – Kanpur* Axisymmetric gas injection in cylindrical vessels is a classical elementary building block for analyzing gas-stirred ladle systems. Consequently, its numerical modeling is a subject of many investigations spanning several decades (1975–2018), which continue to evolve with progress in theoretical, algorithmic and computational efficiency. The present study builds upon well-accepted experimental studies with physical models to critically evaluate the state of the art and outlook of various popular numerical approaches. It discusses the conceptual formulation and approximations of fluid multi-phase, interphase exchanges and resolution of turbulence in the bath. Suitability and drawbacks of various assumptions are also examined. Particular emphasis is laid on time averaging (RANS), turbulence modeling, Lagrangian bubble tracking and volume of fluid (VOF) approaches. Apart from being predominant predictive tools, these also serve to supplement more intensive formulations like large eddy simulation. Their adequacy is therefore important for realistic and accurate hydrodynamic simulation. In such context, coupling of Lagrangian tracking and VOF as an economical computational framework is discussed.	**Numerical Study on the Dynamics of Puddle Using VOF and Solidification Models in the Planar Flow Casting** *S. Kim, G. Kim, J. Park, S. Jung, POSCO* The shape of a nozzle applied in planar flow casting process could be of various geometries. Generally, a nozzle with many holes is used for homegeneous flow inside nozzle. But the holes caused inhomogeneous flow inside the nozzle because of the flow resistance at an initial state. Therefore, the flow and temperature field of the molten steel inside the nozzle were investigated over less than 10 ms by numerical simulation. The inhomogeneous flow at the initial state caused an inhomogeneous temperature distribution inside nozzle, then resulted in quality defects of the produced ribbons.
4:30 p.m.	**Thermal Tracking of Ladles** *S. Ferro, C. Cicutti, P. Galliano, Tenaris* Thermal evolution of the refractory lining in the ladles is calculated as they move through the different stations of the steel plant. Temperature equations are solved in the ladle wall, accounting for the properties of the different layers of lining. Different boundary conditions are imposed to the equations according to the process the ladle is undergoing. Physical tracking of the ladles in the plant is carried out by radio frequency identification. Temperature measurements performed in the steel shop were used to validate the model. From the thermal state of the wall, the amount of energy the ladle could extract from the liquid steel is obtained. This indicator is shown to the operators at the electric arc furnace and ladle furnace for them to decide how to drive their processes.	**A Study on the Effect of Fluid Flow Into Non-Metallic Inclusion Changes** *S. Piva, M. Ferreia, D. Kumar, P. Pistorious, Carnegie Mellon University* Fluid flow is important to non-metallic inclusion reaction kinetics for various reasons. When liquid steel is stirred, steel mass transfer coefficient is increased (promoting steel-slag-inclusion-refractory reactions), the mixing time of the melt is lowered and the turbulent collision frequency between particles is expected to increase. In this work, the experimental observations on steel-slag-crucible-inclusion reaction kinetics for induction furnace trials are verified using coupled fluid flow-heat transfer modeling. The calculated turbulent dissipation rate of the melt is used to compare the expected turbulent collision frequency to the case of industry-scale steel processing. The assumption of bulk mixing in the liquid as a rate-liming step for steel-inclusion reactions is also discussed.	**Large Eddy Simulation on the Fluid Flow Inside a Conventional Ladle Shroud System** *J. Zhang, Q. Liu, S. Yang, W. Lin, J. Li, University of Science and Technology Beijing* The conventional ladle shroud (CLS) with a straight bore is the most widely used shroud to transfer steel stream from a ladle to a tundish in steelmaking practices. In this study, large eddy simulation was employed to investigate the flow structure inside a full-scale CLS system with all flow control assemblies considered, including the slidegate, joint nozzles and the ladle shroud. Attempts were made to analyze the distribution of velocity, vorticity, turbulence kinetic energy and dissipation rate. The effect of slidegate opening (100%, 50% and 25%) on the flow structure was considered as well. The results demonstrated that the joint part between the assemblies featured velocity change and thus many vortices were generated. The asymmetric flow was intensified when the slidegate was not fully open.
5 p.m.	Reception		

THURSDAY, 15 AUGUST 2019

TRACK A

SESSION A9: Electric Steelmaking

8 a.m.

Dynamic EAF Process Model – Thermochemistry and Further Development✦

T. Hay, A. Reimann, T. Echterhof, H. Pfeifer, RWTH Aachen University

The presented model is a further development of the electric arc furnace (EAF) process model published by Logar et al. and improved by Meier. The existing thermochemical calculations were replaced by a more detailed model and the concentrations of oxygen and sulfur dissolved in the melt can now be calculated. Different models for the calculation of melt and slag activities were implemented into the model and an additional reaction zone was defined to account for the influence of diffusion within the melt. Furthermore, a new heat transfer model for the electric arc will be implemented. An optimization algorithm was developed to help with the adjustment of empirical model parameters for different furnaces and operation strategies, and the model was made more efficient compared to Meier's implementation allowing for similar execution time in spite of the increased model complexity. For validation, extensive operational data from an industrial EAF are available.

8:25 a.m.

Evaluating Methods of Approximating Arcs Within CFD Models

S. Roberts, T. Echterhof, H. Pfeifer, RWTH Aachen University

The arc in an electric arc furnace is the main power source for the heat transfer and convection taking place in the slag and freeboard gases. An improved understanding of the heat transfer and flow inside furnaces would support furnace design, operation, control and automation. Especially in the context of integrated computational fluid dynamics studies of furnaces and on-line furnace control, approximate arc models are preferred when the alternative of modeling the complete arc physics, with its stochastic nature, is too computationally expensive for these applications. In this work, a number of possible features to be included in such an approximate arc model are investigated and evaluated using computational modeling and sensitivity studies. The investigated features are: the electrode shape, the material properties used to model the slag, the shape of the boundaries representing the arc, and the boundary conditions used to represent the heat and momentum coming from the arc.

TRACK B

SESSION B9: Machine Learning, Big Data and Logistics

8 a.m.

A Review of Data Mining Techniques for Failure Prediction in Continuous Casting

R. Peters, P. Holborn, University of South Wales

The Internet of Things (IoT) has seen an explosion in the development of sensing devices gathering and producing ubiquitous amounts of high volume and velocity data contributing to the big data environment. Today, Industry 4.0 is driving advances in innovative technologies to help digitize manufacturing processes, enabling business to make more informed decisions. Sensors play a fundamental role in either monitoring or controlling the continuous casting process. Sensors continuously collect and transmit measurements and contain rich information about the condition of equipment. This paper explores the use of data mining techniques to generate failure prediction models where the pre-failure conditions are learnt from historical sensor data. The suitability of two failure detection approaches, anomaly detection and classification are reviewed in collaboration with a large steel manufacturer, Tata Steel UK. Ultimately, this information will be applied in real time to predict future failures and to help optimize the scheduling of maintenance.

8:25 a.m.

Understanding Dephosphorization in Basic Oxygen Furnaces (BOFs) From a Data Science Perspective

S. Barui, University of South Alabama; S. Mukherjee, K. Chattopadhyay, University of Toronto

Empirical models developed using plant data are not universal and are too complicated to be used by operators daily. In the current study, a machine learning–based approach was developed to predict phosphorus partition in steelmaking slags containing a $CaO–SiO_2–MgO$ system. A generalized linear model (GLM) and support vector machine (SVM) are proposed to predict the partitioning of phosphorus in the end product steel. GLM is useful when the error distribution is not normal. For such cases predictions through multiple linear, regression could be inaccurate. The optimal set of features is selected by the application of stepwise regression with Akaike Information criteria. The SVM model implemented supervised learning to classify the end product steel into two groups, viz., accepted or rejected for a given set of features. The credibility of SVM is established using a measure of concordance. The SVM algorithm predicted the end product steel as accepted or rejected with 95% accuracy.

TRACK C

SESSION C9: Processing of Advanced High-Strength Steels I

8 a.m.

Development and Application of Performance Prediction Model for Cold-Rolled Products

L. Junyou, B. Xue, Z. Guoqiang, Angang Steel Co. Ltd.

This paper introduces the method of establishing the performance prediction model of cold rolling products by using data resources of steel mills for many years. It includes the process of demand analysis, data collection, data collation, system architecture, data loading and application development. It also combines the principles of metallurgy and materials science, the selection of key influencing factors and the optimization of models. The model was used to optimize the strength of bake hardening steel, and several solutions were given, which were put into practice in production, and finally the optimal quality design was formed.

8:25 a.m.

Rapid Alloy Processing of Dual-Phase Steels

S. Connolly, C. Slater, WMG, University of Warwick; R. Underhill, Tata Steel; C. Davis, WMG, University of Warwick

Rapid alloy processing (RAP) is a small-scale production process allowing the generation, testing and evaluation of new alloys and/or processing parameters within a research lab, or "virtual factory" rather than in the steel plant, dramatically reducing turnaround (up to 100 times faster than current methods) and associated costs. A particular challenge is ensuring that key microstructural features from large-scale industrial manufacture can be replicated at the small scale, an example of which is casting segregation and rolling reduction. Dual-phase steels, used for automotive applications, have a banded ferrite and martensite structure, which requires careful design of the RAP casting conditions (cooling rate and cast size) and rolling reduction to replicate the key microstructural features. This paper compares the outputs from RAP to that from industrial-scale production and discusses the limitations and opportunities that small-scale, rapid prototyping brings to research and development in the steel industry and beyond.

TRACK A | TRACK B | TRACK C

SESSION A9 (cont'd) | SESSION B9 (cont'd) | SESSION C9 (cont'd)

8:50 a.m.

Track A — Session A9 (cont'd)

Numerical Simulation of Oxy-Natural Gas Combustion in an Electric Arc Furnace

G. Tang, Y. Chen, Y. Wang, A. Silaen, Purdue University Northwest; K. Vanover, Y. Krotov, Steel Dynamics Inc.; C. Zhou, Purdue University Northwest

Both electricity and natural gas are input as energy during electric arc furnace (EAF) operation. Economically, it can be advantageous to increase natural gas energy input while decreasing electricity consumption. Oxy-fuel burners firing natural gas are widely applied in EAF operation for steel scrap melting and steel refining. It is critical to understand the characteristics of oxy-fuel combustion in the EAF. Compared to traditional air-fuel combustion, oxy-fuel combustion generates higher CO concentrations in the near-burner region with significantly higher flame temperatures. In order to accurately predict the oxy-natural gas combustion in EAF operation, a three-dimensional computational fluid dynamics model was developed with detailed consideration of different chemical reaction mechanisms and radiation models. Model validations were conducted on the flow properties (velocity, temperature and species concentrations) and flame properties. General criteria for choosing chemical reaction mechanisms and radiation models were proposed for industrial applications.

Track B — Session B9 (cont'd)

Extending Application of Variable Selection Using Random Forest (VSURF) Technique in Prediction of Mechanical Properties of Investment Castings

J.S. Virdi, W. Peng, University of Regina; A.V. Sata, Marwadi Education Foundation Group of Institutes

Investment casting is one of the oldest manufacturing processes and is widely used in different industrial sectors including aerospace, automobile, biomedical, chemical and defense. These industrial castings need to possess mechanical properties, including ultimate tensile strength, yield strength and percentage elongation during its service life. These mechanical properties are mainly driven by process parameters and chemical composition of alloy. In this work, an effort has been made to predict the mechanical properties from input parameters, including 16 process parameters and nine chemical composition of alloy. Input data was collected from industrial investment casting foundry, and its redundancy was eliminated by the VSURF technique. Statistical and soft computing–based techniques were employed for prediction of mechanical properties using reduced data set. Their results were also compared to identify their prediction capability. It can be concluded that artificial neural networks, multivariate adaptive regression splines and Xgboost perform better in prediction of mechanical properties.

Track C — Session C9 (cont'd)

Dual-Phase Steels Produced by Belt Casting

C. Slater, C. Davis, WMG, University of Warwick

The benefits of casting at speeds >60 times that of continuous casting with an energy reduction of >3 GJ/metric ton during production makes belt casting an attractive technology. Although there are many advantages to this process, the accelerated cooling rates on solidification and reduced rolling reduction required can have significant implications on the final microstructure. Dual-phase steels are widely used in the automotive sector with, in some vehicles, almost 45% of the steel being comprised of this high-strength material. The properties of dual-phase steels come almost entirely from the amount and distribution of the two phases present (typically ferrite and martensite). Segregation during solidification means local manganese concentrations vary based on the initial dendritic structure, and subsequent rolling modifies this distribution, which then influences the spatial distribution of martensite. This paper explores the implications and opportunities when producing this family of steel via belt casting.

9:15 a.m.

Track A — Session A9 (cont'd)

Simulation on Scrap Melting in the Steelmaking Process

Y.-L. Zhang, M. Gao, University of Science and Technology Beijing

Scrap melting rate is a key influencing factor on efficiency of the converter steelmaking process. Here, the melting process of scrap cylinder in hot metal was studied by numerical simulation (using Fluent software) coupling heat and mass transfer, and the simulated results agreed reasonably well with those of laboratory thermal tests. It suggested that mass transfer of carbon from the melt to the scrap surface is a limited step. The cylinder made by cast iron was totally melted into hot metal within 19 seconds, while that by scrap took 160 seconds to be melted. Further, the melting mechanism of scrap and mass transfer coefficient of carbon is discussed. Based on the thermal experimental data, the value of the mass transfer coefficient of carbon was evaluated to be around 2.77 $\times 10^{-5}$ m/second.

Track B — Session B9 (cont'd)

Industrial Fan Predictive Maintenance Using Deep Recurrent Neural Network

B. Chen, C. Zhou, L. Wu, A. Silaen, Purdue University Northwest

Industrial fans and blowers play critical roles in manufacturing. Fans running in a good condition deliver stable airflow, which improves efficiency and system reliability in manufacturing. The failure of fans in critical missions will stop manufacturing and may cause significant costs associated with machine repair and production delay. With the advent of smart manufacturing, predictive maintenance can be achieved with the help of sensors, data analysis and predictive algorithms. This paper presents deep learning–based predictive maintenance techniques that serve as an effective way to prevent possible severe system failures in asset-heavy industries. The long short-time memory (LSTM) algorithm was applied on time-series data prediction, and a statistical-based algorithm was proposed that can map the LSTM prediction to a "health index" that can be used to represent the healthy status of the machine system for future maintenance.

Track C — Session C9 (cont'd)

Cellular Automata Modeling of Plastic Deformation in Ferrite During Martensite Formation in Dual-Phase Steels

V. Atreya, Delft University of Technology; C. Bos, Tata Steel Europe; M. Santofimia, Delft University of Technology

The mechanical properties of ferrite-martensite dual-phase (DP) steels are influenced by the internal stresses induced during austenite to martensite transformation. The volumetric expansion during this transformation causes plastic deformation of surrounding ferrite grains and creates regions with higher density of geometrically necessary dislocations near ferrite/martensite interfaces. These highly stressed regions can be modeled using the "core and mantle" approach as a thin layer of hardened ferrite present at ferrite/martensite interfaces. The interface layer properties, i.e., its strength and thickness, depend on surrounding local microstructural features. In the present work, this layer is modeled using cellular automata (CA)–based microstructural evolution simulations, which make it possible to track variations in local microstructural features and assign layer properties accordingly. This new approach enables the computational study of the effect of transformation induced stresses on mechanical behavior of different, fully controlled DP steel microstructures obtained through CA simulations.

TRACK A	TRACK B	TRACK C

SESSION A9 (cont'd)

9:40 a.m.

Detailed Modeling of Radiative Heat Transfer in Electric Arc Furnaces Using Monte Carlo Techniques

J. Hernandez, L. Onofri, Acciai Speciali Terni; S. Engell, Dortmund Technical University

In an electric arc furnace, most of the energy transfer from the arc to the steel occurs via radiative heat transfer. Therefore, the development of a model that accurately describes this phenomenon is key to understanding the dynamics of the melting process of the metal. Despite its importance, radiation mechanisms have been underestimated in studies using parameter-estimation techniques and in those that, assuming simplified geometries, are not dealing with shadings and blockages in view lines. This work proposes a novel first principles model that for the first time explicitly considers view line blockages and shading effects. Radiative exchanges are modeled as a linear resistive circuit that dynamically changes in topology and Monte Carlo simulations are employed for the calculation of the view factors. Numerical results were validated against process data and errors were lower than 5% in terms of melting time, energy consumption and liquid steel temperature.

SESSION B9 (cont'd)

Caster Scheduling Model for Process Optimization

A. Silaen, A. Afsar, H. Zhao, B. Wu, J. Trimble, Purdue University Northwest; D. Grenough, M. Wilke, L. Fabina, J. Mengel, ArcelorMittal USA; and C. Zhou, Purdue University Northwest

The steel industry faces increasing competitive challenges. It is imperative for steel manufacturers to drastically cut costs while improving product quality and customer satisfaction in order to maintain their market positions. One of the tools in the drive to cut costs, increase quality and improve customer satisfaction has been improved planning and scheduling systems. This paper will describe a decision support system for the problem that is faced by ArcelorMittal at Burns Harbor. The system integrates the customer order selection, planning and scheduling of the continuous casters, which then allows for synchronized production.

SESSION C9 (cont'd)

Understanding Thermomechanical Behavior and Castability Issues of Advanced High Strength Steel (AHSS) via Thin Slab Casting Route

T. Bhattacharya, ArcelorMittal Global R&D; N. Poulain, O. Jaouen, TRANSVALOR S.A.

Thin-slab casting is an attractive route for the mass production of next-generation advanced high-strength steels (AHSS). However, a funnel mold poses considerable challenges in terms of castability of these exotic grades. Proper understanding of heat transfer, solidification and thermomechanics, in the context of thermophysical properties of these new grades, is essential to assess the impact of the funnel shape on the stresses in the solidifying shell and the resulting shell buckling and airgap formation in the funnel mold. In the present work, a 3D finite element code, Thercast®, which is being specifically developed to simulate the continuous casting process, was employed to understand the castability issues of next-generation AHSS in thin-slab casting.

10:05 a.m. Refreshment Break

TRACK A	TRACK B	TRACK C

SESSION A10: Recent Advances in Steel Manufacturing

10:40 a.m.

Overview of National and European Research on Continous Casting at SWERIM

P. Ramirez Lopez, P. Jalali, S. Kesavan, T. Forslund, U. Sjorstrom, J. Bjorkvall, SWERIM AB

SWERIM is a Metallurgical, Mining and Materials Institute recently created by the merger of Swerea MEFOS and KIMAB in Sweden. In the past 10 years, the branch located in Luleå (MEFOS) has performed a variety of research projects including European Research Fund for Coal and Steel projects, National research funded by the Innovation and Energy Agencies as well as consultancy projects in the field of Continuous Casting. The present article provides an overview of activities ranging from mould and nozzle design to optimization of caster performance including mould oscillation, argon injection and casting powder performance. These activities are strongly based on modelling complemented with pilot testing as well as development of new measurement techniques. This synopsis aims to describe the State-of-Art on Casting Research in Scandinavia and in Europe from a Research & Development point of view.

SESSION B10: Environmental Impacts

CFDust: Diffuse Emissions Characterization and Modeling Using Image Analysis and CFD Simulation

A.P. Storch, A.C.A. Bernabe, T.V. Gomes, R. Sartim, ArcelorMittal Global R&D Brazil Centre

Diffuse emissions in steelmaking are challenging to quantify and, for several emission sources, there are empirical methods and references in literature for the estimation of required dedusting flow rates, which are related with high uncertainties. Frequently, some process have limited or no information related to emission flowrates, in such a way that dedusting flowrates is often based on suppliers know-how and previous experiences. In this context, this work proposes an innovative methodology for characterizing, modeling and simulating diffuse emissions using imaging processing and ANSYS Fluent. This methodology allows a more accurate estimation of dedusting system flowrate requirements and capture hood design optimization.

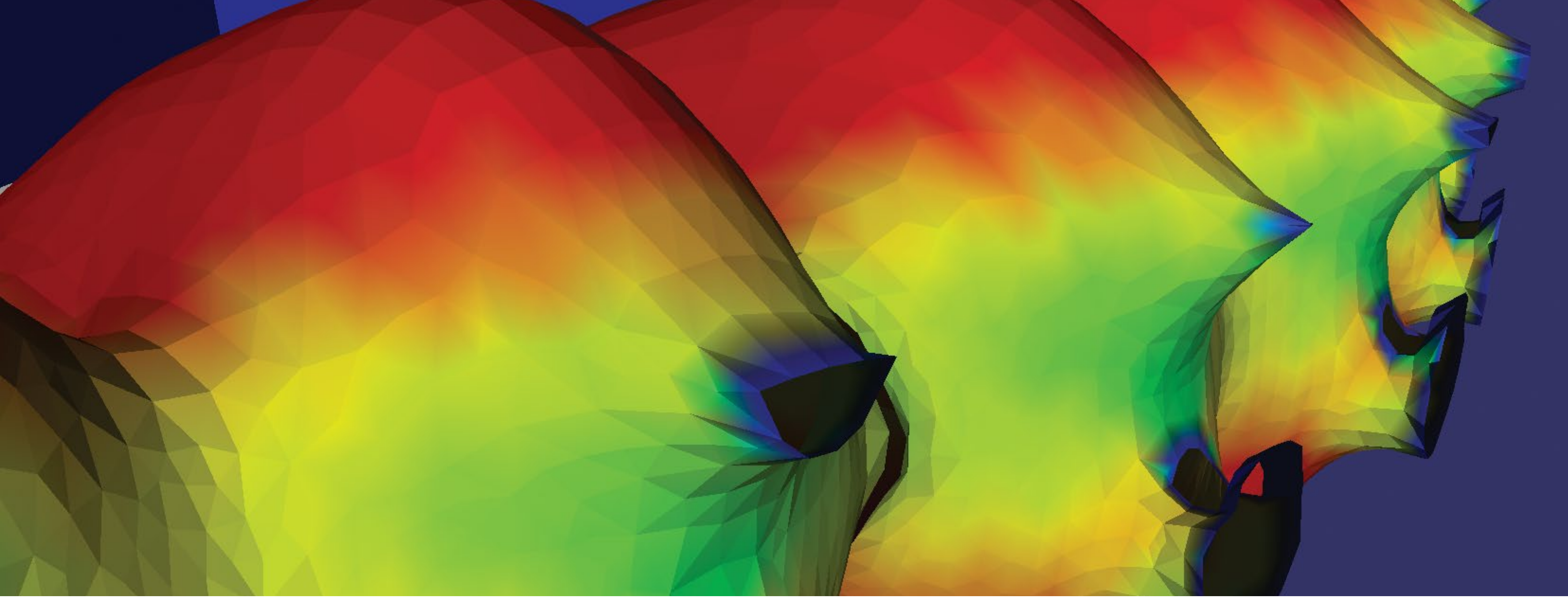
SESSION C10: Processing of Advanced High-Strength Steels II

Prediction of Inclusion BSE Image Grayscale Value From Chemical Composition✦

M. Abdulsalam, B. Webler, Carnegie Mellon University

Analysis of steel cleanliness has been greatly aided by scanning electron microscopy (SEM) coupled with energy-dispersive spectroscopy (EDS). Generally, a large amount of data is generated from SEM/EDS analysis and only size and compositional variables are utilized for inclusion analysis. This study explores some of the visual information, specifically the grayscale value of backscattered electron (BSE) images. This work will attempt to identify connections between the BSE and inclusion composition by applying regression models to predict BSE image grayscale value of inclusions using chemical composition measurements. PENEPMA, a Monte Carlo simulation program, was also utilized to investigate the effect of inclusion size and embedded depth on inclusion grayscale value.

	TRACK A	TRACK B	TRACK C
	SESSION A10 (cont'd)	**SESSION B10 (cont'd)**	**SESSION C10 (cont'd)**
11:05 a.m.	**Reducing Overall Energy Consumption for EAF Operation while Increasing Productivity and Improving Quality** *S. Varkiani, Can-Technologies Inc.* This study proposes a comprehensive modeling and simulation of electric arc furnace (EAF), considering electrical, metallurgical and operational aspects of the furnace process, with the aim of reducing tap-to-tap time and energy consumption while increasing productivity and improving steel grade quality. Two case studies conducted in a Chinese plant concluded that employing advanced, intelligent and yet practical modeling and simulation techniques for arc stabilization, arc length control, energy and mass balance, endpoint carbon prediction, electrode consumption, heat profile, and oxygen profile were quiet effective and achieved the following optimizations for different steel grades: reduced tap-to-tap time by 32–50%, increased daily output by 50–65% and reduced electrical energy intensity (KWh/ton) by 25–44%. Therefore, it is critical for steel companies to look at all aspects of EAF operations and to employ the latest technologies available in order to achieve maximum benefits and remain globally competitive.	**Numerical Analysis of Slag Transfer in the IronArc Process** *J. Svantesson, M. Ersson, P. Jönsson, KTH - Royal Institute of Technology* The IronArc process is a novel approach to the reduction of iron oxide with the purpose of reducing the total emissions associated with steel production. By using electric energy rather than chemical energy for heating of the reactor, the CO_2 footprint of steel can be significantly reduced. Electric energy is used to power plasma generators that superheat air and liquid petroleum gas (LPG) to temperatures over 4,000 K, which is then blown into the iron oxide slag. The LPG is necessary for the chemical reduction of oxygen present in the iron oxide. Because of the reactive nature of iron oxide–rich slags, the wear on refractory materials used in the reactor and the associated slag runner is of interest. Numerical simulations have been done in ANSYS Fluent to determine gas flow patterns and turbulence behavior near refractory walls, as well as turbulence and heat transfer in the slag runner.	**Ab-initio Guided Design and Materials Informatics for Accelerated Product Development of Next-Generation Advanced High-Strength Steels (AHSS)** *A. Datta, C. Zhou, Purdue University Northwest* This paper will introduce a high-performance computing–driven approach to accelerated development of next-generation advanced high-strength steels (AHSS). A multi-scale approach to alloy design will be discussed that will bridge the gaps between the atomic scale (e.g., starting with chemistry/atomic arrangements) and the macroscopic scale (e.g., to predict mechanical behavior of automotive components). Other intermediate-scale or mesoscopic information (such as microstructure that embeds processing information) will also be incorporated to enrich and inform a chemistry-process-structure-property correlated product development strategy. An example will be provided around a promising AHSS candidate ($FeTiB_2$) to demonstrate how quantum mechanical or first-principles calculations such as density functional theory could be used to screen promising candidate chemistries. Finally, a road map will be proposed to build a materials informatics platform by utilizing the vast amount of data generated from these multi-scale calculations and other sources (such as lab/industrial trials, literature data, etc.) to evaluate promising chemistries rapidly using the recent advances in machine learning and artificial intelligence techniques.
11:30 a.m.	**Application of a Mixed Fluid/Structure Model for Ingot Casting Simulation and Macrosegregation Prediction** *O. Jaouen, N. Poulain, Transvalor; J. Demurger, D. Poirier, Ascometal* In the process of ingot casting, multiple considerations related to metal solidification, porosities, segregation and grain structure are definitively of prime concern, as they directly impact the final properties of the subsequent forged or rolled component. This paper focuses on a recent 3D fluid/structure model implemented into the so-called commercial software THERCAST®. The model involves a turbulent fluid flow and the solid constitutive equation. Because of the coupling with the behavior equations, the solidification structure can be accurately modeled as well. In that context, French steelmaker Ascometal has conducted finite element method simulations based on 3D fluid/structure model to validate the design of larger than usual ingots and to guarantee an optimal quality. Comparisons between experiment and simulation results are presented, including central porosities together with the influence of the ingot size over macrosegregation phenomena.	**Potential of Energy Savings by Simulation and Optimization of an Integrated Iron and Steel Plant** *Q. Zhang, S. Liu, S. Xie, Z. Wei, T. Zhao, Northeastern University* Iron and steel manufacturing process is an energy- and material-intensive process, which requires a large amount of energy and emits more pollutant, such as CO_2. It is necessary to pay attention to energy savings and CO_2 emission due to increasingly severe environmental challenges in the iron and steel industry. This paper proposed a combined model including long-route iron and steel production and a complex energy network that contains byproduct gases, steam and electricity network, and the optimization model and case study are also established for energy use and CO_2 emission. The results show that the simulation and optimization model are effective for analysis and the energy use will decrease through the waste heat recovery and energy efficiency technologies adopting. The analysis also shows that most of the parameters have a coefficiency nexus with energy use and CO_2 emissions.	**Effects of Different Melting Rate in GH4151 Superalloy by VAR Numerical Simulation** *J. Qu, Central Iron & Steel Research Institute; Z. Chen, J. Li, S. Yang, University of Science and Technology Beijing* The process of vacuum arc remelting (VAR) solidification was studied by computer simulation technology, which can effectively predict the influence of process parameters on the shape of the metallic bath and the microstructure of the ingots. Therefore, in this paper, the VAR solidification process model was established based on Procast and Visual Studio software, and the morphology and dendrite arm spacing of the metallic bath under different melting rates during vacuum arc remelting GH4151 were simulated. The results showed that, with the increase of melting rate, the depth of metallic bath increases, but the time required to establish a stable metallic bath was reduced, and the primary and secondary dendrite arm spacing of the ingots from center to edge were also reduced accordingly, the results in good agreement with the experimental results.
Noon	Conference Adjourn		



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