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Metallurgical and Materials Transactions B, April 2016

Limitation of sulfide capacity concept for molten slags. I. Jung, E. Khoonsari

The sulfide capacity concept has been widely used in pyrometallurgy to define sulfur removal capacities of slags. Typically, the sulfide capacity is considered to be a unique slag property depending only on temperature regardless of partial pressures of oxygen and sulfur. In the present study, it is demonstrated that sulfide capacities of slags in particular those of Na2O-containing slags can vary with partial pressures of oxygen and sulfur due to large solubility of sulfide in Na2O-containing slag systems.

Effect of magnesia-carbon refractory on the kinetics of MgO-Al2O3 spinel inclusion generation in extra-low oxygen steels. C. Liu, F. Huang, J. Suo, X. Wang

MgO-base refractory and MgO bearing slag both have the potential to supply Mg to the molten steel and then prompt the spinel generation. In this article, the effect of MgO-C refractory on the kinetics of spinel transformation was investigated on a laboratorial scale by inserting a MgO-C refractory rod into the Al-killed molten steel. With the refractory/steel reaction time increasing from 1 to 10 minutes, inclusions of
Al₂O₃ gradually degraded into MgO·Al₂O₃ spinel and the high MgO content inclusion was finally equilibrium with the MgO-C refractory. This interaction process involved Mg supply reactions, Mg transfer in molten steel, and spinel generation reactions. Although MgO-C refractory could supply Mg into the molten steel through MgO reduction reaction both by Al in the melt and by carbon in the refractory, it was found that the Mg mainly came from MgO reduction by the carbon in the refractory. Mg transfer in molten steel was set as the rate controlling step of spinel generation according to theoretical analysis. A mathematical model was developed based on this rate controlling step, and the model calculation agreed well with the experimental results. The Mg diffusion rate was obtained by the regression of the experimental results as 5 x 10⁻⁴ m/s. The mechanism of MgO·Al₂O₃ generation was clarified, and the reaction between dissolved Mg and Al₂O₃ inclusions occurred first and then the extra dissolved Mg reacted with dissolved Al to generate MgO·Al₂O₃.

ISIJ International, February 2016
Phosphate, phosphide, nitride and carbide capacity predictions of molten melts by using an artificial neural network approach. B. Derin, E. Alan, M. Suzuki, T. Tanaka
In the present study, the impurity capacities (Ci) of phosphate, phosphide, nitride and carbide in binary and multi-component molten melt systems at different temperatures were estimated using the artificial neural network approach. The experimental data taken from the previous studies were introduced to the artificial neural network, then the calculated results were plotted against the experimental values for comparative purposes. Besides, iso-phosphate capacity contours on the liquid region of CaO-CaF₂-Al₂O₃ ternary phase diagram at 1 773 K were generated and plotted by using the neural network model results. The calculated results obtained through neural network computation agreed well with the experimental ones and were found more accurate than those estimates based on some models.

Morphology evolution and phase interactions of Fe-containing Si₃N₄ in vacuum high-temperature environment. B. Li, J. Chen, M. Yan, J. Su, J. Sun, Y. Li
To study the substitution of Fe₃Si–Si₃N₄ for refractories in the upper RH refiner, this paper simulated the service condition of RH refining and studied the change of the Fe₃Si–Si₃N₄ in the simulated condition. A Fe₃Si–Si₃N₄ specimen prepared by flash combustion was put in a vacuum sintering furnace with carbon lining, fired at 1 450°C under 80 Pa of vacuum degree for 2 h, and then cooled. The morphological evolution before and after being treated and phase interactions of the Fe₃Si–Si₃N₄ specimen were studied and analyzed thermodynamically and dynamically. The results show that at high temperatures in vacuum, Fe volatilizes from the Fe₃Si melt in Fe₃Si–Si₃N₄ and reacts with Si₃N₄ on the Si₃N₄ crystal surface, forming new FexSi melt there; then Fe continues to volatilize from the new FexSi melt, causing FexSi alloy particles finer and more uniform in Fe₃Si–Si₃N₄; the hexagonal columnar Si₃N₄ crystals begin to decompose partially, and become cylindrical with edges and corners disappearing; during prebaking or operation interval of RH refining, a SiO₂ film which has better stability than Si₃N₄ is developed on the surface of Si₃N₄ crystals or Fe₃Si–Si₃N₄ bricks, preventing the decomposition of Si₃N₄ and improving the application feasibility of Fe₃Si–Si₃N₄ in RH refining.

Relation between electrical conductivity and viscosity of CaO–SiO₂–Al₂O₃–MgO system. W. Li, X. Cao, T. Jiang, H. Yang, X. Xue
Alternating current impedance method has been used to measure the electrical conductivity of CaO–SiO₂–Al₂O₃–MgO system and viscosity of this system has been measured by high temperature rheometer at the same time. It is found that measured data of electrical conductivity and viscosity showed a relatively high accuracy. A relation between the two parameters has been estimated using a formula which showed a relatively lower deviation compared to the precious work. Ionization theory
Visualization study on the droplet evolution behaviors in electroslag remelting process by superimposing a transverse static magnetic field. H. Wang, Y. Zhong, Q. Li, Y. Fang, W. Ren, Z. Lei, Z. Ren

A transparent experimental model had been built to visualize the electroslag remelting (ESR) process. With the help of the transparent model, the evolution of the droplet happening at the tip of the consumable electrode was recorded clearly by a high-speed camera with the record frequency of 200 frames per second. Firstly, the physical simulations were done under different intensities of the transverse static magnetic field (TSMF) with a constant remelting current of 8 A. Then the experiments were carried out at different intensities of the remelting current with a constant TSMF of 0.7 T. The representative processes of the droplet evolution under different conditions were demonstrated. When the external TSMF was large enough, a special phenomenon was discovered: The liquid neck connecting the end of the electrode with the droplet would become longer, and then an inflated liquid bulge appeared in the middle of the liquid neck. After a short while, the liquid metal neck was smashed into a lot of smaller droplets by the strong electromagnetic vibration. The results under different conditions indicated that the smashing effect acting on the droplet neck would be improved with the enlarging of the external TSMF at the constant remelting current, but it got worse under the condition of a higher remelting current. The mechanism of the smashing effect was well discussed.

Numerical investigation on the effect of slag thickness on metal pool profile in electroslag remelting process. Q. Wang, B. Li

A transient three-dimensional (3D) model was developed to understand the role slag thickness plays in the formation of the metal pool in the electroslag remelting (ESR) process. In this model, the solution of the mass, momentum and energy conservation equations were simultaneously implemented by the finite volume method with full coupling of the Joule heating and Lorentz force by solving the Maxwell’s equations. The movement of metal droplet was described by volume of fluid (VOF) approach. Additionally, the solidification was modeled using an enthalpy-based technique, where the mushy zone was treated as a porous medium. The experiment and simulation demonstrated a reasonable agreement. The results indicate that changing the slag thickness changes the slag temperature, but not monotonically. The slag temperature drops with the slag thickness up to 60 mm, beyond which the slag temperature rises. The melt rate decreases and then increases while the cooling intensity remains unchanged. As a consequence, the maximal metal pool depth reduces from 0.081 m to 0.067 m and slightly increases to 0.074 m.

Materials Science and Technology – Electrical Processing of Materials, October 2015


The refinement of inclusions in molten steel induced by a continuous electric current pulse was investigated at 1823 K. The results revealed that due to the application of electric current, the melted sulphide inclusions in molten steel were refined. Analysed from the thermodynamic theory, the refinement mechanism was ascribed to the decrease in the system free energy that resulted from the formation of the refined sulphide inclusions in molten steel at 1823 K. Hence, the electric current pulse treatment may be a new method to refine inclusions in molten metallic materials in the future.

Journal of Material Science, October 2015
**Prediction of intragranular ferrite nucleation from TiO, TiN, and VN inclusions**
Wangzhong Mu; Par Goran Jonsson; Keiji Nakajima

The current study presents a method to calculate the critical diameters of TiO, TiN, and VN inclusions for intragranular ferrite (IGF) nucleation in steels. Based on the calculation results, it was noted that the critical diameters of TiO, TiN, and VN inclusions for IGF nucleation were 0.192, 0.355, and 0.810 μm. The calculation results agreed with the experiment data of a minimum inclusion size for IGF nucleation in the actual steel samples. Moreover, the effects of Mn, C, and S contents on the critical diameters of inclusions were investigated. It was found that the critical diameters of TiO, TiN, and VN inclusions increased with the increasing Mn and C contents. In addition, it was found that S does not have a direct effect on the critical diameters of TiO, TiN, and VN inclusions. However, the increasing S content led to an increased amount of MnS precipitation in the actual steels. This is negative, since MnS is ineffective nucleation site for IGF nucleation. When the amount of MnS increases in steels, the area fraction of IGF slightly decreases. This fact has been investigated by in situ observation experiments.

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**Ironmaking & Steelmaking, October 2015**
**Structural viscosity model for aluminosilicate slags.** Q. Shu, X. Zhang, K. Chou

Based on the structure of aluminosilicate slag, a new model has been proposed for viscosity calculation of aluminosilicate slags. Contributions of bridging oxygen (O-), non-bridging oxygen (O2) and free oxygen (O-2) to viscous activation energy were modelled. Compositions of three types of oxygen were calculated from optical basicity values by combining the Toop–Samis model with a correlation between reciprocal of optical basicity and polymerisation extent proposed by Ottonello and Moretti. Charge compensation equilibrium among charge compensated Al, cations for modifying network and Al with no charge compensating cations was considered. The model has been applied in calculations of viscosity of the Al2O3–CaO–MgO–SiO2 system. Good agreement between calculated and measured viscosity with a mean deviation of less than 25% was achieved. Since most viscosity measurements for molten slag at high temperature were subject to an experimental uncertainty of 25%, the present model could provide accurate viscosity values for slag systems investigated.

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**Steel Research International, September 2015**

The effect of the Ti, Al contents on the metamorphic evolution of inclusions of Ti–Al complex oxides including TiN and MnS are investigated in common carbon steels with TiO2 and TiN particle additions. The study is carried out based on both SEM-EDS analyses and Thermo-Calc equilibrium calculations. Moreover, the particle size distributions are investigated by using the electrolytic extraction method. Based on the results of this study, the following is suggested: (i) the steel composition is controlled to contain small amount of the Al content (0.035 mass%) in order to obtain a high number of fine particles containing a Ti-rich oxide phase when adding TiO2 and TiN particles; (ii) this consideration is reasonable from the view point of the agglomeration degree of different inclusion materials, which are estimated from the attractive force (van der Waals force and liquid-capillary force) and the contact angle.

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**METEC & 2nd ESTAD, June 2015**
**Automation solutions for economical and ecological upgrade of steelmaking plants.** J. Mellenthin, J. Thomasberger, D. Ehler.

In steelmaking process, where up to 70% of variable cost of finished product is already incurred, energy and refractory costs account for 45-50% of the cost of production of crude steel and contribute significantly to the carbon footprint of the end product. Any
attempt to control and reduce these costs will automatically lead to more competitiveness and reduced carbon emissions. Leading the technology for ECOPLANT (characterized by the fact that the economic and ecological benefits are integral part of our products), SMS has developed innovative solutions which can be applied to both new and existing plants alike. This paper reviews some of these electrical and automation concepts. The most direct approach to increasing the energy and process efficiency is the use of intelligent control units, where the measurements of different field equipment are interconnected and evaluated. At the EAF, for example, the X-Pact FEOS optimizes different forms of energy input like electricity, fuel, carbon and oxygen while at the same time increasing the refractory lifetime and reducing the tap-to-tap time. Tackling the secondary gas cleaning system and hence being applicable to almost all steel plants, the X-Pact Gas Cleaning Assistant optimizes the control of individual dampers based on modelling of fluid resistances of ductwork in gas cleaning system. It guarantees the best dust removal from work place at minimum energy consumption. Other X-Pact systems complement the automation system from the management and optimization point of view. The X-Pact Ladle Management System, by managing ladle running operations for reduced ladle waiting times, improves the average thermal content of the ladle and thereby reduces the oil/electricity/refractory consumption. The X-Pact Energy Advisor is an energy data management system which analyses the consumption of various forms of energy for all plant units and helps finding and evaluating improvement potential. With inclusion of process information, the energy efficiency can be continuously supervised, reducing the data to key performance indicators and helping to move towards better energy productivity.

A model for sequencing and optimizing steel melt shop operations using discrete event system simulation. A. Mukherjee, A. Adak
This paper presents how steelmaking throughput improvement study using simulation helped to identify the bottlenecks causing capacity loss and experiment with options to redesign the system by suggesting mechanisms for improvement and additional facilities and logistical resources. From a unit optimization perspective, it is essential that the BOF does not have any wait time other than the preparation time. Liquid steel is moved to the casters from the BOF via LRF and for some grades VD, such that the heat sequences for different grades are maintained while maximizing the utilization of the casters. The simulation model of the steel-melting-shop unit included all these elements and constraints to reflect the behaviour of the unit in operation. Based on the objective of maintaining the sequence continuity in the casters while maximizing its utilization, our simulation model helped discover the bottleneck due to BOF delays and the number of existing LRFs. Redesigning and simulating again yielded the changes in BOF, optimal number of LRF units, the optimal number of hot metal ladles and steel ladles in active circulation and also ensured maximum possible capacity utilization and throughput in the melt shop.

Comprehensive process optimization system for JSW Steel Toranagallu. R. Hubmer, J. Weiss, N. Desai
The JSW Steel Ltd has become India’s largest private sector steel company with an installed capacity of 14.3 MTPA. The JSW Steel Vijayanagar plant in Toranagallu is the first integrated steel plant in India to reach 10 MTPA capacity in a single location. In October 2013 JSW Steel decided to place an order to Primetals Technologies Austria (former Siemens VAI Metals Technologies) for the installation of a comprehensive Level 2 process optimization system for more than 20 existing production facilities of various suppliers. For SMS-I new L2 systems are provided for two hot metal pretreatment stations, three hot metal desulphurization stations, three ladle furnaces, two 1-strand slab casters, a ladle tracking system as well as a shop supervisory system. Additionally, the existing L2 system for one 1-strand slab caster is being upgraded in the course of the project. In SMS-II new L2 systems for the 7 hot metal desulphurization stations, 4 ladle
furnaces, 1 new RH vacuum degasser, ladle tracking system and a shop supervisory system are supplied. Following the challenging time frame from JSW Steel Ltd the acceptance test has been passed in July 2014 and the commissioning of the single facilities started within less than 12 month after contract effectiveness. This paper describes the installed Primetals Technologies process optimization systems and their integration into the JSW automation environment. Furthermore it gives a characterization of the course of the project and focuses on achieved results.

In the past years, the trend was going into the direction of using dry mechanical pump systems for Vacuum Degassing plants, especially for heat sizes below 150t for pure degassing operation (VTD). For VOD operation there are only few references with mechanical pump systems. Special attention has to be paid with respect of safety during oxygen blowing and not only to the correct design according to the process. Primetals Technologies addressed all these points and was proving its know-how for such kind of process and equipment in a European special steel plant. An outlook will be given also for the RH-OB-process. As a second highlight of vacuum treatment, we want to introduce a new RH lifting system: The new RH CVL system raises the bar of flexibility. The demand of modern steel plants is constantly changing. Variation of production speed, material flow and logistics will influence the decisions for a certain lifting system as part of a degassing concept more and more. Additionally, many needed modernizations and upgrades have to cope with numerous existing steel plant limitations. The new RH CVL (Combined Vessel and Ladle lifting) System provides the flexibility you deserve. With a very small footprint it combines ladle lifting and vessel exchange capabilities. It gives an optimized logistics solution being accessible from both sides and allows a “drive-through” material flow. Even RH treatment in areas unreachable for cranes will be possible.