（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Fundamentals of High Temperature Processes

Simulation of gas–liquid flow in dripping zone of blast furnace involving impermeable fused layers

G.X.WANG et al.

A newly developed gas–liquid two-phase model has been employed to simulate the flow of gas and liquid in a blast furnace. This model accounts for the existence of impermeable fused layers in the blast furnace cohesive zone and treats the liquid as a discrete phase as revealed by experimental observation. The model has been run with a variety of assumed cohesive zones under a given blast furnace condition, giving the flow pattern and the distributions of liquid flow rates and liquid holdup. The results demonstrate the localized horizontal or upward flow characteristics of discrete liquid in and below the blast furnace cohesive zone. These characteristics are affected by the cohesive zone structure that can be described in terms of shape, position and the numbers of fused layers. The study reinforces the need to implement liquid flow in blast furnace modelling.

(cf. *ISIJ Int.*, **40** (2000), 627)

Steelmaking

Transient mathematical model of blast furnace based on multi-fluid concept, with application to high PCI operation

J.A.CASTRO et al.

The ironmaking blast furnace is a counter current chemical reactor whose main purpose is to produce hot metal (pig iron) from iron oxides. In the furnace, five phases: gas, lump solids (iron ore, sinter, pellets and coke), liquids (pig iron and molten slag) and powders (tuyere injectants: pulverized coal, coke fines or dust from the lump coke) interact with one another. In order to evaluate productivity, energy efficiency and transient phenomena occurring in the blast furnace, a comprehensive two-dimensional transient mathematical model has been developed. The model was composed of conservation equations of mass, momentum, chemical species and thermal energy for all phases mentioned above. This model includes phase transformations and chemical reactions such as melting of pig iron and slag components, moisture evaporation, reduction of iron oxides, solution loss, coke and pulverized coal combustion, silica reduction and gas phase reactions. With this model, the transient behavior of the blast furnace process has been successfully predicted for different injection rates of pulverized coal.

(cf. *ISIJ Int.*, **40** (2000), 637)

Introduction of pisolitic goethite ore into a Chinese ore blend

L.YANG et al.

Research has been carried out to examine the effects of introducing an Australian goethitic ore (*i.e.*, Yandi ore) into a Chinese sintering ore blend. Bench-scale studies show that Yandi ore is easier to be assimilated than hematite ore, which agrees with that observed in blending with hematite ores. Substitution of Yandi ore for an Australian hematite in the blends does not lead to significant changes in sinter mineralogy.

Effects of adding Yandi ore on sintering performance was studied by conducting pot tests under simulated conditions of this Chinese sinter plant. It has been found that when an Australian hematite ore is replaced with Yandi at 10–40% in blends, at slightly increased mix moisture, productivity maintains or increases slightly, coke rate maintains and sinter strength shows a marginal increase with increasing Yandi ore. At Yandi ore levels of 10–40%, the productivity is about 1.47–1.51 t/m^{2}h at mix moistures of 7.2–7.3%, ISO tumble index of the sinters is around 69%, coke rate is about 50 kg/t. The low coke is probably due to the easy-melting property of Yandi ore, possible oxidation of the magnetite concentrates, etc. JIS reducibility of the sinters increases from 60% to 68% when the goethite ore level varies from 10% to 40% in the blends.

This work evidences that Yandi ore can be used successfully to replace hematite ores in Chinese type blends.

(cf. *ISIJ Int.*, **40** (2000), 647)

Steelmaking

Methods of increasing the rate of tin evaporation from iron-based melts

L.SAVOV et al

The low evaporation rate is a main obstacle to the large scale application of vacuum refining of steel scrap melts with respect to tin. In this paper several possibilities of increasing the evaporation rate of tin have been investigated. Iron-based melts containing 0.3 to 0.6 mass% Sn were treated in a laboratory-scale vacuum induction melting furnace at a pressure of 10 Pa.

It was confirmed that detinning is enhanced by increasing the sulphur content of liquid iron. This effect is explained by the evaporation of volatile SnS. The kinetics of SnS evaporation is discussed.

(2) Evaporation of volatile SnO from steel melts containing less than 0.024 mass% oxygen was not confirmed.

(3) The highest evaporation rate of tin in elemental state is observed from high-silicon iron melts. The most favourable conditions occur at approximately 22 mass% Si in the iron melt. This fact is discussed in terms of the thermodynamics of the liquid Fe–Si–Sn system.

(4) New process schemes of tinplate scrap recycling are considered. It is suggested to use tinplate scrap as iron-bearing material for the production of ferro-silicon alloys. The recycling of tinplate scrap in the ferro-silicon production has potential benefits over its recycling in steelmaking.

(5) It is demonstrated that the condensate gathered during vacuum refining of tinplate scrap melts can be reprocessed in the non-ferrous industry to obtain pure tin.

(cf. *ISIJ Int.*, **40** (2000), 654)

Thermodynamic model for ternary silicate systems

J.GUTIERREZ et al.

A thermodynamic model has been developed for the representation of ternary liquid silicate systems SiO_2–AO–BO, where A and B are metals such as Ca, Fe, Mn, *etc.* It is based on a structural model which assumes that each metallic oxide produces the depolymerization reaction $O^\circ + O^{2-} = 2O^-$ with a characteristic free energy change. The model can calculate the properties of ternary systems solely from data of the binary sub-systems. No ternary terms are required.

The model is used to calculate the activities of the components in complex silicates such as SiO_2–FeO–CaO where the behavior of Fe^{2+} is very different from that of Ca^{2+} in the silicate structure. This model has been also used to calculate the activities in the systems SiO_2–MgO–FeO, SiO_2–MgO–CaO, SiO_2–MgO–MnO, SiO_2–Na-O–MgO and SiO_2–Na_2O–CaO. Good agreement is obtained between calculated and experimental results.

(cf. *ISIJ Int.*, **40** (2000), 664)

Casting and Solidification

Numerical simulation of the coupled turbulent flow and macroscopic solidification in continuous casting with electromagnetic brake

D.-S.KIM et al.

A computer program has been developed for analyzing the three-dimensional, steady conservation equations for transport phenomena in a slab continuous casting process with Electromagnetic Brake (EMBr) to investigate the effect of EMBr on the turbulent melt-flow, temperature fields, and macroscopic solidification of the molten metal. The enthalpy-porosity relation was employed to suppress the velocity within a mushy region. A revised low-Reynolds number k–ε turbulence model was used to consider the turbulent effects. The electromagnetic field was described by Maxwell equations. The application of EMBr to the mold region results in the decrease of the transfer of superheat to the narrow face, the increase of temperature in free-surface region and most part of the melt of submold region, and the higher temperature gradients near the solidifying shell. The increasing magnetic flux density has effect mainly on the surface temperature of the solidifying shell at the narrow face, hardly on that at the wide face. It is seen that in the presence of EMBr, a thicker solidifying shell is obtained at the narrow face of slab.

(cf. *ISIJ Int.*, **40** (2000), 670)

Crystallographic relationships between δ-ferrite and γ-austenite during unidirectional solidification of Fe–Cr–Ni alloys

S.FUKUMOTO et al.

The crystallographic orientation relationships between δ-ferrite and γ-austenite during unidirectional solidification of Fe–Cr–Ni alloys have been evaluated with EBSPs (Electron Back Scattering Patterns). The preferred orientation relationship between δ and γ agrees with the Kurdjumov–Sachs (K-S) relationship in both rod and lamellar eutectic structures obtained by Bridgman experiments. It is thought that the preferred relationship is developed by nu-

cleation of secondary phase. The orientation relationship between primary γ-dendrites and primary δ-dendrites during dissimilar alloy welding (primary γ to δ-dendrites) by a laser experiment also agrees with the K-S relationship. The transition from primary γ to δ-dendrites is thought to be controlled by heterogeneous nucleation of ferrite at the growing γ-dendrite front. It is suggested that the nucleation also plays an important role in the microstructure formation.

(cf. *ISIJ Int.*, **40** (2000), 677)

Model study on the entrapment of mold powder into molten steel

M.IGUCHI et al.

In continuous casting molds of steel, mold powder is placed on the meniscus of molten steel in order to prevent heat loss from the meniscus and to use it as a lubricant between the solidifying steel and the mold. The mold powder is sometimes entrapped into the molten steel. Such mold powder entrapment affects the quality of the steel product significantly. In this study we focused on the shear flow instability between the molten steel flow and mold powder as one of causes for the mold powder entrapment and investigated the effect of the kinematic viscosity of the mold powder on the onset of the entrapment. Model experiments were carried out using salt water and some kinds of silicone oils. The velocity of flow around an interface between the silicone oil and salt water was measured with a particle imaging velocimetry (PIV) based on the cross-correlation method. The kinematic viscosity of silicone oil hardly affected the critical flow velocity for the onset of the mold powder entrapment caused by Kelvin–Helmholtz instability, but it affected the wave length of the instability.

(cf. *ISIJ Int.*, **40** (2000), 685)

Forming Processing and Thermomechanical Treatment

Effects of coiling temperature on microstructure and mechanical properties of high-strength hot-rolled steel plates containing Cu, Cr and Ni

S.-J.KIM et al.

In this study, four kinds of high-strength hot-rolled steel plates were fabricated with additions of tramp elements of Cr and Ni to a basic C–Mn–Si–Cu steel, and their microstructures and mechanical properties were investigated to analyze the effects of coiling temperature and tramp elements. When the steels were coiled at 400°C, their volume fraction of retained austenite was lower than the case of coiling at 450°C. The steels containing Cr individually or together with Ni had the volume fraction of retained austenite above 10%, but showed the characteristics of dual phase steels having high tensile strength and low elongation as a large amount of austenite was transformed to martensite during cooling. In the case of coiling at 450°C, both elongation and strength–elongation balance were increased owing to the increase in the fraction of retained austenite and the transformation induced plasticity (TRIP) effect. The addition of Ni resulted in a great increase in the fraction of retained austenite at the higher coiling temperature, thereby improving tensile strength and elongation.

(cf. *ISIJ Int.*, **40** (2000), 692)

Welding and Joining

Effect of gap filler and clearance of gap on microstructure of wide-gap brazing seam

J.ZHANG et al.

The influence of gap filler content, gap filler powder size and clearance of gap on the microstructure of the brazing seam was investigated. The volume fraction of the eutectic plus the intermetallic compound and the number of voids in the brazing seam were used to evaluate the factor. The results show that the content of gap filler affects the microstructure of the brazing seam greatly, while the gap filler powder size and the clearance of the gap have little effect on it.

(cf. *ISIJ Int.*, **40** (2000), 699)

Surface Treatment and Corrosion

In Situ electrochemical atomic force microscopy study with atomic resolution of Fe(110) in sodium sulfate aqueous solution

N.HIRAI et al.

In situ electrochemical atomic force microscopy (EC-AFM) was used to investigate a bare Fe(110) and an anodically formed oxide on Fe(110) in 0.05 M Na_2SO_4 aqueous solution under potential control. An unreconstructed Fe(110)–(1×1) structure was observed at −1.9 V in 0.05 M Na_2SO_4 aqueous solution by keeping the potential in hydrogen evolution region for 10 min. This is the first *In situ* EC-AFM image with atomic resolution of unpassivated iron electrodes under aqueous solution. We also observed $Fe(OH)_2(0001)$–(1×1) structure of an anodic oxide layer grown on Fe(110) single crystal at −1.2 V in 0.05 M Na_2SO_4 aqueous solution. From these EC-AFM investigation, we have found an epitaxial relationship of $Fe(OH)_2(0001)[2\bar{1}\bar{1}0]$// $Fe(110)[1\bar{1}0]$ between the anodic oxide layer and Fe(110) substrate.

(cf. *ISIJ Int.*, **40** (2000), 702)

Numerical analysis of fluid flow and heat transfer in molten zinc pot of continuous hot-dip galvanizing line

Y.H.KIM et al.

A numerical model adopting a partially staggered grid system for the location of dependent variables has been developed to analyze the fluid flow and temperature distributions in a molten zinc pot of No. 2 CGL of POSCO Kwangyang strip mills. A control volume based finite difference procedure was employed to solve the conservation equations transformed by using the boundary-fitted-coordinate (BFC) system. The calculation results have shown that a change in the steel strip velocity has little influence on the overall flow pattern developed in the pot. The overall temperature distribution was rather uniform as predicted. However, charging cold ingots directly into the pot produced a non-uniform distribution of temperature. The local temperature fluctuations will promote the formation of intermetallic dross particles. It has been proposed that the non-uniform distribution of temperature could be reduced by selecting an appropriate channel inductor position as well as by optimizing the zinc ingot loading position.

(cf. *ISIJ Int.*, **40** (2000), 706)

Transformations and Microstructures

Modelling the austenite to ferrite phase transformation in low carbon steels in terms of the interface mobility

T.A.KOP et al.

The kinetics of the phase transformation between the high temperature FCC-phase austenite and the low temperature BCC-phase ferrite as it occurs during controlled cooling of hot rolled low carbon steels is described using a physical model that considers austenite grain size, nucleus density, composition effects, and the austenite/ferrite interface mobility. The model is verified against experimental dilatometry data for three lean carbon-manganese steel grades. The model yields adequate reproductions of the transformation kinetics. Ferrite grain coarsening during the transformation appears to have a significant effect on the final microstructure.

(cf. *ISIJ Int.*, **40** (2000), 713)

Aging behaviour of 25Cr–17Mn high nitrogen duplex stainless steel

I.F.MACHADO et al.

The precipitation behaviour of a nickel free stainless steel containing 25% chromium, 17% manganese and 0.54% nitrogen, with duplex ferritic–austenitic microstructure, was studied using several complementary techniques of microstructural analysis after aging heat treatments between 600 and 1 000°C for periods of time between 15 and 6 000 min. During aging heat treatments, ferrite was decomposed into sigma phase and austenite by a eutectoid reaction, like in the Fe–Cr–Ni duplex stainless steel. Chromium nitride precipitation occurred in austenite, which had a high nitrogen supersaturation. Some peculiar aspects were observed in this austenite during its phase transformations. Chromium nitride precipitation occurred discontinuously in a lamellar morphology, such as pearlite in carbon steels. This kind of precipitation is not an ordinary observation in duplex stainless steels and the high levels of nitrogen in austenite can induce this type of precipitation, which has not been previously reported in duplex stainless steels. After chromium nitride precipitation in austenite, it was also observed sigma phase formation near the cells or colonies of discontinuously precipitated chromium nitride. Sigma phase formation was made possible by the depletion of nitrogen in those regions. Time–temperature–transformation (precipitation) diagrams were determined.

(cf. *ISIJ Int.*, **40** (2000), 719)

A model for the cottrell atmosphere formation during aging of ultra low carbon bake hardening steels

J.Z.ZHAO et al.

A model describing the formation of the carbon atmosphere around a dislocation during aging of vacuum degassed ultra low carbon bake hardening steels has been developed by extending the original Cottrell theory taking into account the effects of the variation of the free carbon concentration, the saturation of dislocations and the segregation of carbon atoms to grain boundaries. Strain aging experiments have been carried out with an ultra low carbon steel and the experimental results been compared with the theoretical predictions. It is demonstrated that the model developed can describe the formation of Cottrell atmosphere in ultra low carbon bake hardening steels in industrial circumstances.

(cf. *ISIJ Int.*, **40** (2000), 725)