Fundamentals of High Temperature Processes

Multi-frequency electromagnetic stirring of liquid metals

K.-H.SPITZER et al.

In some applications of electromagnetic stirring of metals a characteristic flow pattern is requested in the melt which requires a certain volume force distribution. The possibilities to achieve such a volume force distribution by a suitable geometry and position of the stirrer are limited. More flexibility is obtained when the stirring is performed with two or more magnetic fields traveling with different velocities in different directions. It is shown in the present paper that such a stirring can be realized with a conventional stirrer by feeding its three-phase winding with a current made up by superposition of two or more currents with different frequencies and traveling directions.

Ironmaking and Reduction

Radial distribution of burden descent velocity near burden surface in blast furnace

M.ICHIDA et al.

An examination was made in regard to the influences of various factors on descent characteristic at a free surface and inner burden based on the model experiment and measurements at an actual furnace. At the same time a non-uniform descent model was prepared and a study was conducted with the use of a non-uniform descent model as to a mechanism forming the radial distribution of burden descent velocity near the burden surface in a blast furnace. As a result, the following knowledge has been acquired. The relative burden descent velocity at the free surface is relatively larger at the peripheral area and smaller at the central area than that at the inner burden. The relative burden descent velocity at the peripheral area on the free surface is large when a peripheral ore/coke is high or there is a wall erosion at the upper part of shaft. Non-uniform descent characteristic at the free surface is remarkable for alumina ball and sintered ore having a small repose angle and not remarkable for coke having a large repose angle. In the actual operation, radial distribution of relative burden descent velocity near the burden surface greatly varies depending on a relative ore/coke distribution, difference in particle size between coke and sintered ore and physical property values, even if the charging pattern is the same.

Steelmaking and Refining

Numerical simulation of three-dimensional fluid flow and mixing process in gas-stirred ladles

M.-Y.ZHU et al.

A numerical study was performed for the three-dimensional turbulent fluid flow and mixing characteristics in gas-stirred ladles with a code developed by present authors. The effects of gas flow rate, positions of nozzle and tracer, and inclined wall on the flow pattern and mixing were investigated in the present work. It is shown that eccentric blowing increases the azimuthal velocity, thus reducing the mixing time, and the mixing time is sensitive to the alloy/tracer adding position especially for center blowing. For the ladle with inclined wall, it has shorter mixing time compared with the cylindrical one. The predicted results were compared with the experimental data, which showed good quantitative agreements.

Ferrous oxide activity in $FeO-TiO_2-CaO-Al_2O_3$ system

M.M.ELISSA et al.

Ferrous oxide activity has been determined in molten synthetic slag mixtures of the quaternary system $FeO-TiO_2-CaO-Al_2O_3$ at constant levels of Al_2O_3. Furthermore, in the course of determining the FeO activity in this quaternary system, the ternary system $FeO-CaO-Al_2O_3$ was also investigated at 1450°C.

The technique used to measure the ferrous oxide activity in the investigated systems was the well established one of gas-slag-metal equilibration in which molten slags contained in armco iron crucibles are exposed to a flowing gas mixture with a known oxygen potential until equilibrium has been attained. After equilibration, the final chemical analysis of the slags give compositions having a particular ferrous oxide activity corresponding to the oxygen potential of the gas mixture.

The effect of Al_2O_3 additions on the FeO activity was determined. The results are presented as a series of iso-activity curves on pseudo-ternary diagrams. The interdependence between the ferrous oxide activities and slag composition was also studied.

Phosphorus distribution ratios between $CaO-SiO_2-Fe_tO$ slags and carbon-saturated iron at 1573K

J.IMAMURA et al.

In response to recent industrial demands for refining hot metals without using halides at the lowest CaO consumption, the possibility of hot metal dephosphorization by $CaO-SiO_2-Fe_tO$ slags of low CaO content has been assessed in this study. In order to clarify the dephosphorization behavior of hot metals, equilibrium distribution ratios of phosphorus between $CaO-SiO_2-Fe_tO$ slags and solid iron strips have been measured as a function of slag composition at 1,573K, avoiding CO gas evolution if carbon-saturated iron is used. The obtained distribution ratios have been converted to those for hot metals using available thermodynamic data of phosphorus in solid and liquid irons.

Phosphorus distribution ratio strongly depends on CaO content but not so much on Fe_tO contents of the slag. It increases with an increase in CaO content when Fe_tO content is kept constant, while it slightly decreases when total Fe content is increased from 18-24 mass% to 55 mass% at the (mass% CaO)/(mass% SiO_2) ratio of around unity.

Phosphate capacities have also been estimated using activity data for FeO in this slag system, being considerably affected by CaO content of the slag. They show a good correlation with slag basicity.

The kinetics of dissolution of copper in aqueous cupric ammine solutions

S.UCHIDA et al.

The dissolution rate of metallic copper plate in aqueous cupric ammine solutions was studied at 0.05~1.0mol/l$CuSO_4$ concentration, 0~3000rpm rotation speed and temperatures between 10~90°C. The dissolution rate was mainly controlled by chemical reaction at temperatures below 30°C, and by diffusion of cupric complex at temperatures higher than 40°C. It was found that the dissolution rate of copper increases with an increase in temperature and rotation speed, while a maximum rate was observed for increasing Cu (II) concentration. The effect of different anion showed significant results on dissolution rate of copper and iron, and carbonate ion was found to prevent the corrosion of iron.

Thermodynamics on control of inclusions composition in ultra-clean steels

H.SUITO et al.

The relations among the compositions of inclusion, steel and top slag were thermodynamically studied at 1823 K in tire cord, valve spring, ultra low carbon sheet, bearing and sultur free-machining steels. In case of a tire cord and valve spring steels, the equilibrium among inclusion, steel and top slag was found to be established in practice with respect to Si and Mn. The contents of Si, O and Ca in an ultra low carbon sheet steel were determined as a function of top slag composition, and the higher oxygen contents observed in practice were explained by the effect of Fe_tO in slag. Thermodynamic discussion were made for the formation of spinel inclusions in a bearing steel and the precipitation of CaS in a sulfur free-machining steel.

Casting and Solidification

Effect of the primary oxide on the behavior of the oxide precipitated during solidification of steel

H.GOTO et al.

Effect of the primary oxide on the behavior of the oxide precipitated and grown during solidification was investigated using Mn deoxidized steel which has primary oxides and soluble oxygen before solidification of the steel. The composition and size of oxides in the continuously cast steel were observed and theoretically analyzed. The results obtained are as follows.

MnO-FeO and MnO-FeO-Al_2O_3 oxides were observed. The compositions of the oxides change with cooling rate of the steel and the size of oxide. The Al_2O_3 content of the oxide at low cooling rate is lower than that at high cooling rate. The Al_2O_3 content of the oxide decreases with the decrease in the size of the oxide.

As a result of the theoretical analysis of the oxide behavior during solidification on the basis of a diffusion growth model, it has been found that MnO-FeO oxide precipitates and grows regardless of primary oxide during solidification and MnO-FeO-Al_2O_3 oxide grows during solidification as MnO precipitates on the primary oxide which cotains Al_2O_3.

Physical and mathematical modeling of steel flow and heat transfer in tundishes under non-isothermal and nonadiabatic conditions

J.DE J.BARRETO SANDOVAL et al.

Steel flow and heat transfer in tundishes under non-isothermal and non-adiabatic conditions are physically and mathematically modeled. For this purpose thermal step inputs in both types of models are applied and temperature measurements as well as computations of flow and heat transfer at unsteady state are carried out.

Experimental measurements of output responses to thermal step inputs fed in the tundish model and the transient solution of the three dimensional Navier-Stoke's equations keep a very good agreement.

Isothermal lines of water model and those belonging to the prototype under non-adiabatic conditions are not equivalent for the same thermal step input and this promotes different velocity fields of water in the model and liquid steel in the prototype.

As velocity fields have a direct influence on inclusions removal from steel to the covering tundish slag it is recommended to have caution on the employment of non-isothermal water models to interpret the actual behavior of steel flow and inclusions dynamics in industrial tundishes.

Instrumentation and Control System

Modelling and simulation of hydraulic gap control system in a hot strip mill

P.BHOWAL et al.

Hot strips are presently being rolled out with considerable thickness accuracy. This has been made possible due to superordinated control system comprising of adaptive setup model, monitor thickness control, automatic gauge control, tension and looper control, hydraulic gap control etc.

The present work is, however, confined to modeling and simulation studies of hydraulic gap control system in the last stand of the finishing mill of a typical hot strip mill (HSM). The simulation results based on the model show that the system operates effectively to provide high thickness accuracy and good response behavior.

Forming Processing and Construction

Effect of hot band annealing temperature on the magnetic properties of low-carbon electrical steels

C.-K.HOU

The effect of hot band annealing temperature, range from 700-1 000°C, on the magnetic properties of low-carbon electrical steels measured at 10, 15 and 17 kG inductions have been investigated. The grain microstructures of hot bands were changed by annealing at various temperature. Small grains are observed in the as hotrolled band and hot band annealed at 700°C. Large columnar grains are observed in the hot band annealed at 800°C. Duplex structure with fine grains at the central portion of the plate and large columnar grains near the surface are observed in the hot band annealed at 900°C. Uniform medium size grains are observed in the hot band annealed at 1 000°C. In addition, the size of manganese sulfide inclusions in the hot bands increased with increasing annealing temperature. After final annealing at 820°C for one minute, grain size of low-carbon electrical steels increased with increasing hot band annealing temperature. After final annealing, low-carbon electrical steel with hot band annealing at 800°C developed favorable texture for magnetic properites. At three different inductions, ac core loss and hysteresis loss decreased with increasing hot band annealing temperature in 700-900°C. At 10 kG induction, ac and dc permeability increased with increasing hot band annealing temperature. Low-carbon electrical steel with hot band annealing at 800°C exhibited maximum ac and dc permeability under 15 kG induction. However, the steel with hot band annealing at 900°C obtained maximum ac and dc permeability and maximum magnetic flux density under 17 kG induction. Magnetic properties of the steel were improved when hot bands were annealed at temperature higher than 800°C, when it was compared with the as hotrolled steel.

Reduce rolling characteristics of hollow piece by rotary rolling mill

K.NAKASUJI et al.

Extra-thick-walled tubes, hollow rods, in which wall thickness to outside diameter ratio is 25 % or more, are produced at steel rod rolling mills at large, as they cannot be manufactured into seamless tubes at any existing mill plant. They are currently produced by a process in which a square billet with an inserted mandrel of manganese steel is passed through a bar mill. Then, the hollow billet is finished to the desired diameter and wall thickness. After that, the mandrel is removed from the hollow billet. The unit tool requirement of this process is costly and uneconomical, and the dimensionally accuracy is low.

In this paper, the reduce rolling characteristics of hollow piece by rotary rolling mill have been studied in detail. This process, in which a rotary rolling mill with three rolls has been used for reducing the outside diameter of hollow piece, makes it possible both to obtain hollow rods with high dimensional accuracy and to produce hollow rods efficiently. This rotary rolling makes it possible to reduce the outside diameter of hollow pieces and to control the wall thickness of hollow pieces with no internal sizing tool by only setting rotary rolling mill conditions. Hollow pieces having the desired dimensions can be produced with high accuracy.

Surface Science and Technology

Texture formation of TiN films deposited on (011) [100] single crystal of silicon steel

Y.INOKUTI

In order to clarify the texture of TiN deposited onto (011) [100] single crystals of silicon steel, TiN ceramic coating by the HCD method was done on the surface of polished silicon steel samples. Pole figures of the TiN films and related silicon steel samples were measured simultaneously using an SSD auto pole figure apparatus.

$(111)_{TiN}$ pole figure of the TiN film showed the dominant texture of $(1\bar{1}1)$ [110] orientation, and $(100)_{Si-steel}$ pole figure of the (011) [100] single crystal of silicon steel showed the dominant texture of (011) [100] orientation. The orientation relationship between the TiN films and a single crystal of silicon steel is considered to be $(1\bar{1}1)_{TiN}//(011)_{Si-steel}$, $[110]_{TiN}//[100]_{Si-steel}$.

It should be noted that the dominant texture of TiN with $(1\bar{1}1)$ [110] orientation was formed preferentially on the surface of (011) [100] single crystal of silicon steel, and the orientation relationship between the TiN films and a

single crystal of silicon steel was very good misfit within several percent.

Morphology and crystallography of hcp Zn crystals electrodeposited on bcc Fe-3% Si single crystal substrates

T. FURUHARA et al.

The morphology and crystallography of Zn crystals electrodeposited on Fe 3 mass% Si ferrite single crystal substrates was examined for various substrate orientations. The epitaxy between the Zn crystals and the ferrite substrates exists on both polycrystalline and single crystal substrates. Zn crystals deposited on the (100)b, (110)b and (111)b substrates have four, one and three variants of the habit plane, respectively. Zn crystals on the (510)b substrate exhibit more than two variants of the habit plane. Zn crystals deposited on the (110) b substrate have the Burgers orientation relationship with the substrate. The morphology and crystallography of Zn crystals can be explained by the formation of invariant lines on the microscopic {110}b facets of etch pits formed prior to the deposition.

Microstructure

The self-accommodation and plastic accommodation effects during the formation of $\{259\}_f$ lenticular martensite

S. XIAOYAN et al.

From the crystallographic analysis on the micro-structure of the $\{259\}_f$ lenticular martensite observed by using the electron microscope, twins and dislocations in a martensitic plate are closely related to each other and they play important role in the self-accommodation and the plastic accommodation effects in the formation and growth of the $\{259\}_f$ lenticular martensite.

Effects of boride former elements on recovery and recrystallization of reverse-transformed austenite in Fe-19% Ni alloy

T. YASUNO et al.

Effects of various boride former elements (Ta, W, Nb, Ti, Mo) and/or B on recovery and recrystallization of reverse-transformed austenite were examined in carbon-free Fe-19mass% Ni alloys. The combined addition of Nb and B was found to be the most effective in suppressing them; the recrystallization temperature of the reverse-transformed austenite rose up to 1200 K which is ~100 K higher than that of alloys with single addition of boride former element or B. TEM observation of extraction replicas indicated that the retardation of recovery and recrystallization was due to very fine precipitates of Nb-boride. It was made clear from the theoretical analysis on the solubility product of several MB_2-type borides (M=Cr, Mn, Nb, Ti, Mo) that NbB_2 was the most stable over a wide range of temperature (773-1173 K). This may be the reason why recovery and recrystallization do not occur up to the highest temperature in case of the combined addition of Nb and B.

Ferrite grain refinement by large reduction per pass in non-recrystallization temperature region of austenite

A. KOJIMA et al.

In order to clarify the effects of reduction per pass in non-recrystallization temperature region of austenite (γ) on ferrite (α) grain size of low carbon steels, isothermal hot compression tests have been performed. The hot deformations have been carried out by the constant reduction per pass of 10, 20 or 30 % under the cumulative reduction of 30 or 50 % in the non-recrystallization region. The α grain size is decreased about 15 % with increasing the reduction per pass from 10 to 30 % under the cumulative reduction of 50 %. At this time, the α nucleation site density, which is defined as the number of γ grain boundaries, deformation bands and annealing twin boundaries per unit length of deformation direction, is increased about 30 %. It is estimated that the increase in the α nucleation site density is caused by the increase in deformation bands. Furthermore, the number of α nuclei per unit length of γ grain boundaries is increased about 10 % with increasing the reduction per pass from 10 to 30 % under the cumulative reduction of 30 %. It has been clarified by the calculation that the α grain refinement by the large reduction per pass is mainly caused by the increase in the α nucleation site density, which is led by the increase in deformation bands.