Fundamentals of High Temperature Processes

Heat recovery of LDG by utilizing latent heat and reaction heat for producing methanol

N.MARUOKA et al.

This paper proposes a new heat recovery process of hot gas exhausted from the steelmaking converter by utilizing not only latent heat but also endothermic heat of reaction. The intermittently emitted LD gas was first transferred into continuous, constant-temperature heat source in the form of latent heat in the Phase Change Material (PCM) of copper. Then, the stored heat was supplied to Coke Oven Gas (COG) to induce endothermic reaction of methane steam reforming. Methanol was finally produced from the obtained gas in the proposed system. A heat and material balance model predicted all operating data of the system and then exergy analysis based on the predicted data was conducted to validate the system theoretically. The results showed that the proposed system has a possibility to produce a large amount of methanol corresponding to 20% of total demand in Japan, with only 28% of exergy consumption in the conventional method.

(cf. *ISIJ Int.*, **42** (2002), 1189)

The coanda effect on bubbling jet behind a horizontally placed circular cylinder

K.SASAKI et al.

The motions of bubbles and liquid behind a circular cylinder placed horizontally in a vertical water-air bubbling jet were experimentally investigated. Bubbles approaching the cylinder were separated by the cylinder in the two ways along the side wall of the cylinder, and they gathered together again at a certain distance from the cylinder due to the Coanda effect. This situation was confirmed from the measurements of gas holdup and mean water velocity components. The mean bubble diameter behind the cylinder became small because disintegration of bubbles took place around the cylinder. The mean bubble rising velocity also became very low behind the cylinder. The horizontal spreading of the bubbling jet was significantly suppressed by the cylinder.

(cf. *ISIJ Int.*, **42** (2002), 1196)

Ironmaking

Numerical investigation of simultaneous injection of pulverized coal and natural gas with oxygen enrichment to the blast furnace

J.A. de CASTRO et al.

The multiple injection of carbonaceous materials and oxygen enrichment in the blast furnace has received especial attention in the recent years due to its possibility of considerably decrease in coke rate and increase of the productivity. This paper introduces a modeling of the co-injection of pulverized coal and natural gas into the blast furnace through the tuyere. This model treats the blast furnace as a multi-phase reactor and five phases are treated simultaneously: gas, lump solids (iron ore, sinter, pellets and coke), pig iron, molten slag and pulverized coal. Conservation equations for mass, momentum, energy and chemical species are solved simultaneously based on the finite volume method. Firstly pulverized coal is simulated and afterwards only natural gas is investigated and compared with the all coke operation. Finally, the combined practice is suggested in order to improve the actual blast furnace operation. The simulation results have contributed to better understanding the blast furnace phenomena with multiple injectants, and supported new improvements in the furnace operation. The results obtained in this investigation have shown the possibility of considerable advances in the actual blast furnace operation such as increase in productivity, lower silicon content in hot metal and decrease of the coke and slag rates. In addition, the total amount of the greenhouses in the off gas is decreased, which contributes to make the blast furnace process cleaner.

(cf. *ISIJ Int.*, **42** (2002), 1203)

Activation of deadman state in blast furnace using deadman blowing method

K.KUNITOMO et al.

In order to cope with superannuated coke ovens and to reduce pig iron cost, high-rate pulverized coal injection technology and operation technology utilizing inexpensive raw materials and fuels have been examined. The influence on the blast furnace operation to which such technology is applied is that gas permeability in a lower part of the blast furnace, especially inside the deadman of the blast furnace, deteriorates and the temperature of the part decreases. To lessen these drawbacks, new deadman methods for controlling temperature and improving gas permeability were developed. In one of these methods, called the "insert and blowing method", a pipe is inserted into the deadman through a tuyere and then hot gas is blown through the pipe. In another method, called the "boring and blowing method", a coke bed in a lower part of the furnace is bored using a pipe before hot gas is blown through an ordinary tuyere. To confirm and to evaluate the effects of these methods, many experiments using models have been conducted. The results show that gas permeability was improved and the temperature in the lower part of the models was increased. The effectiveness of these methods was increased by adding water vapor to the blowing air when the surface of the deadman was covered with fine coke or char.

(cf. *ISIJ Int.*, **42** (2002), 1212)

Steelmaking

Physical model study of selective slag splashing in the BOF

M.J. LUOMALA et al.

Steelmaking converter vessels do not usually wear evenly. Often, the higher wear rate in the trunnion area determines the lining life of the vessel. On the other hand, major skull growth may occur in other parts. In order to ensure consistent BOF performance, maintaining the vessel geometry by selective slag coating is important. Since selective slag splashing is difficult to perform by conventional oxygen lance, the effect of *e.g.* plugging one or two lance nozzles on the amount and direction of splashing was investigated by physical model experiments. Furthermore, the model was used to predict the influence of lance height, lance position, bottom blowing configuration and liquid viscosity on splashing behaviour. Lowering the lance increased the rate of splashing to a certain lance height beyond which it decreased. Similar behaviour was found to apply also to the slag wash coating mechanism. At low lance distance, plugging one lance nozzle increased the amount of splashing on charge pad and trunnion areas and decreased on slag hole side. Generally, bottom blowing increased the amount of slag drops considerably. Positioning of bottom stirring plugs had a clear effect on the direction of splashes.

(cf. *ISIJ Int.*, **42** (2002), 1219)

Casting and Solidification

The influence of hydrogen on the visibility of pencil pipe defects

O.DANKERT et al.

During casting of interstitial free steel, argon bubbles are caught in the solidification front of the steel slab. During downstream processing, these bubbles develop into sub-surface defects called blowholes or pencil pipe defects. Atomic hydrogen can enter the steel in the pickling line and accumulate in the defects, causing an increase of the internal pressure. In the presented study, blowholes are charged with hydrogen both electrochemically and by exposing the blowholes to pickling acid. The pressure and composition of the gas inside the blowholes are determined by opening the blowholes under ultra high vacuum conditions. It is shown that the accumulated pressure is capable of deforming the blowholes plastically, enhancing the visibility of the defects in the sheet. Calculations of the threshold pressure for plastic deformation show to be in reasonable agreement with measured pressures inside the blowholes. Industrial pickling conditions are discussed as well. It is concluded that hydrogen does not influence the blowholes significantly for the considered industrial conditions. Most likely the blowholes become visible in sheet steel at recrystallisation annealing. The final shape of the blowholes is determined by the temper rolling process.

(cf. *ISIJ Int.*, **42** (2002), 1225)

Material evaluation to prevent nozzle clogging during continuous casting of Al killed steels

Y.VERMEULEN et al.

Al_2O_3–carbon composite submerged entry nozzles (SEN) are used for continuous casting of steels. Although this material has excellent mechanical and thermal properties, it frequently leads to clogging. The purpose of our research is to find a suitable refractory material that can be used to coat SENs. This paper reports on the chemical compatibility of a number of potential refractory materials: Al_2O_3, ZrO_2, Al_2O_3–carbon, SiO_2 and MgO with liquid steel, an amount of simulated inclusions and synthetic slag. For this purpose, an experimental labora-

tory procedure was optimised to simulate the nozzle behaviour during continuous casting. Al_2O_3 was found to give satisfactory results, and therefore a Al_2O_3 plasma coated Al_2O_3–carbon material was also tested in the laboratory with good results.

(cf. *ISIJ Int.*, **42** (2002), 1234)

Effects of secondary flow on the electromagnetic separation of inclusions from aluminum melt in a square channel by a solenoid

D.SHU et al.

Effects of secondary flow of the melt on the separation of inclusions from molten aluminum flowing in a square channel by a solenoid were investigated theoretically and experimentally. Numerical methods were used to calculate the secondary flow, the separation efficiency of inclusions, and the particle motion. It is found that there appear two recirculating loop flows in a quarter cross section of the channel and the separation efficiency of inclusions is significantly improved by the secondary flow mainly owing to the mixing effect. The separation efficiency increases with the increase of the effective magnetic flux density and the frequency of magnetic field, and decreases significantly with the increase of the size of the separator channel for a constant value of a/δ. However, it is possible to achieve high separation efficiency by using large-sized square channels and high frequency magnetic field with the help of the mixing effect of secondary flow. The computed results of particle trajectories show that the secondary flow accelerates the transportation of the particles from the inner region to the vicinity of the wall and greatly shortens the separation time of those particles. The effects of secondary flow on the separation efficiency were confirmed by comparing the measured separation efficiency with the computed results.

(cf. *ISIJ Int.*, **42** (2002), 1241)

Two-phase flow numerical simulation of molten steel and argon gas in a continuous casting mold

N.KUBO et al.

For steel continuous castings, it is essential to control the molten steel velocity at the meniscus, since the velocity is closely related to surface defects on the resultant products. Argon gas is supplied with molten steel into the mold through a submerged entry nozzle to prevent clogging. In this study, to investigate the influence of argon gas on molten steel flow, a numerical simulation was carried out for several casting speeds. The simulation result of a higher casting speed is similar to a casting case in which argon gas is not used. The simulation result of a lower casting speed indicates that as argon gas bubbles ascend near the nozzle, they induce the molten steel to flow with them. The surface velocity magnitude of a lower casting speed is reduced more due to the dispersion by argon gas floatation. In consequence, meniscus molten steel flows from the nozzle to the narrow face of the mold. This flow direction is opposite to a higher casting speed case. By balancing the molten steel throughput and the argon gas flow rate, molten steel flow patterns can be controlled. We can conclude that the argon gas flow ratio is an important element to control the product quality.

(cf. *ISIJ Int.*, **42** (2002), 1251)

Numerical analysis of the influences of operational parameters on the fluid flow in mold with hybrid magnetic fields

Z.-D.QIAN et al.

A package of computer programs, which can be used to calculate magnetic fields, induced current, meniscus shape, and fluid flow was developed and applied to the numerical study of effect of hybrid magnetic fields mold. In investigation about the influence of important operating parameters on the effect of hybrid magnetic fields mold, three standards like the followings were used: the flow pattern, the maximum velocity beneath the meniscus, and the dynamic pressure on the contact point. It was found that the hybrid magnetic fields mold has the effects of both EMBR (Electromagnetic Brake) and soft contact EMC (Electromagnetic continuous casting) at the same time. On the other hand, the hybrid magnetic fields mold can overcome some shortcomings of EMBR and soft contact EMC with proper magnitudes of static magnetic flux density and suitable relative position of the two magnetic fields.

(cf. *ISIJ Int.*, **42** (2002), 1259)

Forming Processing and Thermomechanical Treatment

Laser engraving of micro-patterns on roll surfaces

J.UH et al.

A pattern engraving method was developed with argon ion laser combined with an electro-optic (E-O) modulator and its control units. Image data was first encoded, processed and transferred to the laser modulator after which the patterns were printed on a photosensitive polymer coated on the cold mill roll surface. Once the pattern printing was complete, the roll was put through an etching process for final pattern engraving. Experimental results provide validation that the proposed technology and its performance are quite promising. This developed technology is fairly general and multiple patterns can be imprinted on any target body with the resolution of the μm unit.

(cf. *ISIJ Int.*, **42** (2002), 1266)

Surface Treatment and Corrosion

Analyses of microarc oxidation coatings formed on Si-containing cast aluminum alloy in silicate solution

W.XUE et al.

A dense ceramic coating up to 130 μm thick was deposited on high silicon cast aluminum alloy by microarc discharge in silicate electrolyte. Its microstructure and composition were analyzed by scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS), and phase identification was performed by X-ray diffraction (XRD). In addition, the distributions of hardness, H, and elastic modulus, E, across the ceramic coating were determined by nanoindentation method. The coating has a three-layer structure. The profiles of H and E in the coating are similar. From the surface to the inner layer of the coating, H and E gradually increase. The inner layer is dense and hard, in which the H and E can reach about 15 GPa and 250 GPa, respectively. This coating consists of mullite, γ-Al_2O_3, γ-Al_2O_3 and amorphous SiO_2 phases. The surface layer enriched in Si element has a high fraction of amorphous SiO_2, where the Si element comes mainly from the electrolyte rather than the alloy substrate. However, the Si element from Al–Si substrate enhances the formation of mullite phase in the coating.

(cf. *ISIJ Int.*, **42** (2002), 1273)

Transformations and Microstructures

Recrystallization textures in cold-rolled Ti bearing IF steel sheets

S.-H.HONG et al.

The evolution of recrystallization textures in cold-rolled Ti bearing interstitial free (IF) steel sheets were investigated using X-ray pole figures and electron back scattering diffraction (EBSD). A hot band of IF steel was cold-rolled by 50, 80, and 95%. The deformation texture of cold-rolled steel sheets consisted approximately of the ⟨110⟩//RD (α fiber) and the ⟨111⟩//ND (γ fiber) with high densities in the {001}⟨110⟩, {558}⟨110⟩, and {665}⟨110⟩ orientations. When annealed at 695°C, the cold rolled sheets developed a recrystallization texture characterized approximately by the γ fiber whose main components were approximated by {111}⟨112⟩, {334}⟨483⟩, and {665}⟨1 1 2.4⟩ which is almost the same as {554}⟨225⟩. The densities of these orientations increased with increasing cold-rolling reduction. The recrystallized {111}⟨112⟩, {334}⟨483⟩, and {665}⟨1 1 2.4⟩ grains were attributed to the {001}⟨110⟩, {558}⟨110⟩, and {665}⟨110⟩ deformation orientations by the strain energy release maximization (SERM) model for recrystallization texture, in which the absolute maximum internal stress direction in the deformed state tends to be parallel to the minimum Young's modulus direction of recrystallized grains.

(cf. *ISIJ Int.*, **42** (2002), 1278)

Influence of Al and Nb on optimum Ti/N ratio in controlling austenite grain growth at reheating temperatures

M.CHAPA et al.

On the basis of steel 38MnSiVS5 a high number of castings were manufactured varying only the Ti and Al contents and obtaining ingots in which the Ti/Al ratio was different in each case. The specimens will be heated in air furnace to different austenitization temperatures, between 900°C and 1 200°C, and subsequently quenched in water. The most important achievement would be that Al plays a harmful role as an austenite grain controller at high temperatures (>1 050°C), as a consequence of the quick dissolution of AlN particles and therefore the reduction in inhibition forces at the grain boundaries which are intercepted by them. The best

austenite grain control was shown by steel with contents of Ti=0.044, Al=0.009, N=0.0131 (mass%) and a Ti/N ratio of 3.36. But the interpolation of the results allows it to be concluded that the best Ti/N ratio would be close to 2.5. It was also found that the control of austenite grain size improved with an addition of Nb. In paralell, a study of precipitate sizes was carried out using transmission electron microscopy (TEM) and scanning electron microscopy (SEM).

(cf. *ISIJ Int.*, **42** (2002), 1288)

Morphology of sulfide formed in the Fe–Cr–S ternary alloys

H.MITSUI et al.

The evolution of sulfide morphology in the Fe–(0.3–18)mass%Cr–(0.05–0.3)mass%S alloys during solidification and heat treatment was investigated by means of optical microscopy, scanning electron microscopy, analytical electron microscopy and X-ray diffraction. *In situ* observation of the formation of the fine particle sulfide was also conducted at elevated temperatures by confocal scanning laser microscopy. The morphology of sulfide in the Fe–Cr–S ternary alloys was found to change from a cell wall type to a globular type with increasing Cr content. Accompanying the phase transformation of the matrix from the δ phase to the γ phase, two types of transgranular fine particle sulfide were formed. One is a fine spherical sulfide formed from the FeS-rich liquid phase through the remelting reaction of $\delta \rightarrow \gamma$+Liq. in less than 5 mass% Cr alloys, and the other is a fine rod-like sulfide formed through the eutectoid reaction of $\delta \rightarrow \gamma$+sulfide in 5 to 13 mass% Cr alloys. The formation mechanism of various types of sulfide morphology was examined based on phase diagram information.

(cf. *ISIJ Int.*, **42** (2002), 1297)

Mechanical Properties

Fracture surfaces and mechanical properties in ductile iron

V.M.BERMONT et al.

This work focuses on qualitative and quantitative studies about the fracture surface topography of ductile cast iron samples having different matrices and sizes.

Parameters such as: a) surface roughness, b) actual fracture surface and c) actual nodule count on fracture surface were defined and calculated for fracture surfaces of several experimental test samples. These parameters were related to the values of mechanical properties measured on the same samples, and empirical expressions were established. These expressions, together with data taken from the fracture surface of a broken part, could allow to estimate the critical level of stress and deformation which acted on the part.

(cf. *ISIJ Int.*, **42** (2002), 1303)

Creep behavior at the intercritical HAZ of a 1.25Cr–0.5Mo steel

S.FUJIBAYASHI et al.

Nowadays the preferential creep damage accumulation at the Intercritical HAZ (ICZ) leading to Type IV cracking has been a great concern for various industries. The ultimate failure of the welded components fabricated from ferritic steels often takes place at this particular region. Type IV cracking has been found in almost all the ferritic steel weldments so far, from a conventional 1.25Cr–0.5Mo steel to a modified 9Cr–1Mo steel. However, the mechanism of Type IV cracking has not yet been understood equivocally. In the present work, cross-weld creep behavior of a service exposed 1.25Cr–0.5Mo steel has been examined in order to clear the feature of Type IV damage. The discussion shall be made on the important role of grain boundaries around small grains, which was transformed into austenite during welding, to promote Type IV cracking. The evident feature of grain boundary facets suggests strongly that Type IV cracking is induced by the grain boundary sliding around small grains. Significant impurity segregation, which is expected to accelerate the damage development by stabilizing cavities, was found at grain boundaries.

(cf. *ISIJ Int.*, **42** (2002), 1309)