Fundamentals of High Temperature Processes

Separation of metal droplets from slag

P.K.IWAMASA et al.

The motion of liquid metal droplets in molten slags was studied using low temperature physical modeling and X-ray observations at high temperatures. Experiments were done to assess settling times of metal droplets in slags. Experimental work included oil and water modeling and high temperature experiments utilizing a furnace equipped with an X-ray fluoroscopy apparatus. Results show that settling times of metal droplets in stagnant slags and water droplets in a variety of oils can be accurately predicted utilizing Stokes' equation modified for the appropriate experimental conditions. It was also found that gas stirring in slags, whether by chemical reaction or gas injection, and slag foaming increases droplet settling times. Stable foams resulting from the reaction of FeO in the slag and carbon in the metal as well as gas injection in the metal phase caused rafts to form which could permanently hold droplets up to about 5 mm in diameter at the top of the slag. For better separation, slags with low viscosities are recommended and foaming should be avoided.

Ironmaking and Reduction

Gaseous reduction of MgO-doped Fe_2O_3 compacts with carbon-monoxide at 1173-1473K

A.A.EL-GEASSY

Fired pure Fe_2O_3 and 0.5 - 5.0 % MgO-doped Fe_2O_3 compacts, were isothermally reduced with CO at 1 173-1 473 K. The course of reduction was followed up by thermogravimetric technique. The structure of compacts were microscopically examined while the different phases were identified by X-ray diffraction analysis. Mercury pressure porosimeter was used to characterize the pore structures. The isothermal reduction curves obtained showed that MgO revealed different effects on the reduction behaviour of Fe_2O_3. At the initial stages up 25 % extents, the doping of MgO showed no measurable influence on the reduction process. At the intermediate stages (25-85 % extents), the doping of 0.5 % MgO retarded the reduction while the presence of 1.0 % MgO promoted the reduction of Fe_2O_3. The retardation and promotion effects were increased with the extent of reduction and decreased with rise in temperatures. At final stages of reduction, a slowing down in the rate due to the doping of MgO was observed which was attributed to the formation of hardly reducible magnesiowustite phase. The rate controlling step in the reduction process was determined from the values of apparent activation energy, gas-solid mathematical formulations and the microstructure of partially reduced compacts. It was found that the reduction was controlled by a combined effects of gaseous diffusion and interfacial chemical reaction at the initial stages. While at the latter stages, a solid-state diffusion is contributed to interfacial chemical reaction as the rate controlling mechanism depending on MgO content in compacts.

Suppression of the formation of large pores in the assimilated parts of sinter produced using pisolitic ores

T.OTOMO et al.

Sintering experiments were carried out in order to suppress the formation of large pores existed in the assimilated parts of sinter produced using pisolitic ores. A briquette consisted of disk-shaped pisolitic ore specimen as core particle and fine mixture of hematite ore and limestone as shell layer was used for the experiments. CaO concentration of the shell layer was varied in two levels, *i.e.*, 10 and 26 mass %. The influence of CaO concentration of the shell layer and heating rate on the performance of large pore formation during heating were examined by a microscopic observation. The mean diameter and the area fraction of pores existed in the assimilated part of specimen were also measured. The results obtained were as follows:

By increasing CaO concentration of the shell layer from 10 to 26 mass %, the suppression of the large pore formation was achieved in terms of the decrease in both of the diameter and amount of pores.

The amount of pores decreased with decrease in heating rate over the temperature of melt-formation for both CaO concentration of the shell layer, but heating rate did not influence remarkably pore diameter.

It is clear that the suppressible effect of the increase in CaO concentration of the shell layer on the formation of large pores is resulted from both of the promotion of coalescence of bubbles and decrease in the bubble size possible to move in the melt due to lowering apparent viscosity of the melt formed during heating.

Reduction of CaO and/or MgO-doped Fe_2O_3 compacts with carbon-monoxide at 1173-1473K

A.A.EL-GEASSY

Compacts of Fe_2O_3 doped with either (0.5-5.0 %) CaO, 1.0 % MgO and/or 1.0 % CaO fired at 1 473 K for 20 hrs, were isothermally reduced with CO gas at 1 173 - 1 473 K. Thermogravimetric technique was used to follow up the oxygen weight-loss as a function of time. Partially and completely reduced samples were subjected to chemical and carbon analyses while their internal structure was examined by optical microscope. Pore size analyser was used to characterize pore structure and pore size distribution. The different phases developed during reduction were also identified by X-ray diffraction technique. It was observed that the doping of CaO revealed different effects on the reduction of pure Fe_2O_3 depending on CaO content, temperature and reduction extents. At lower temperatures ($\leq$1 273 K), the doping of $\leq$2.5 % CaO promoted the reduction of Fe_2O_3 and a maximum effect was observed for compacts doped with 1.0 % CaO. At $\geq$1 373 K, the doping of CaO retarded the reduction of Fe_2O_3 at the latter stages due to the sintering and densification effects which increased with temperature. The influence of MgO on the reduction of Fe_2O_3 was discussed in another publication. The doping of 1.0 % CaO with 1.0 % MgO in Fe_2O_3 compacts greatly promoted the reduction of Fe_2O_3 at $<$1 273 K and this effect decreased with temperature. Heterogeneous gas-solid reaction formulations were examined and correlated with both of the apparent activation energies and the internal structures of partially reduced compacts to elucidate the corresponding reduction mechanisms.

Burden descending behaviour with renewal of deadman in a two dimensional cold model of blast furnace

H.TAKAHASHI et al.

The present investigation was intented to elucidate the solid particles behaviour in ironmaking blast furnace when the renewal of deadman coke is going on. The measurement of solid particles velocity was performed with a two-dimensional cold model simulating both consumption of coke in the raceway and renewal of the deadman. The existence of a dynamic boundary for the deadman was clarified by the detailed analysis of the velocity characteristics, and size of the deadman was reduced as the renewal rate increased. The deadman was renewed by the particles fed within a central, limitted area at the top on the bed. Both the critical area and the descending velocity near the central axis of the shaft became large with increasing of the renewal rate. An experimental correlation was obtained to estimate the span of the critical area. Further, it was confirmed for the downflow of particles to rise from the bottom of raceway during renewal.

Thermodynamic properties of the $MgO\text{-}BO_{1.5}\text{-}SiO_2$ system at 1723K

X.HUANG et al.

In order to economically extract boron from a boric oxide bearing iron ore by blast furnace process, thermodynamic properties of the $MgO\text{-}BO_{1.5}\text{-}SiO_2$ system have

been investigated. Phase diagram and the activities of the constituent oxides of the $MgO-BO_{1.5}-SiO_2$ ternary system were determined at 1 723 K by chemical equilibrium method. Thermodynamic calculations for the equilibrium between $MgO-BO_{1.5}-SiO_2$ slag and carbon saturated Fe-B-Si-C alloy were performed and the suitable blast furnace slag composition for the recovery of boron was discussed.

Steelmaking and Refining

Deoxidation of iron melt with immersed MgO-C porous tube

M.AHMADI et al.

In the present study, the deoxidation of iron melt is performed by immersing MgO-C porous tube with and without evacuating its inside. It is found that Mg vapor produced by the reaction between MgO and C of the tube takes part in the deoxidation process. The deoxidation product in a gaseous form (CO) is easily removed from the melt and the product in a solid form (MgO) attaches on the tube surface or floats up to the free surface of the melt. Reducing the internal pressure of the tube enhances the carbon-oxygen reaction. The amount of removed oxygen from the melt increases with initial oxygen content of the melt. This is because of higher efficiency of reaction between Mg vapor and oxygen in the melt. Initial carbon supply from the porous tube is large and hence, the carbon content in the melt increases rapidly at the initial stage of the reaction. At higher initial oxygen content, intensive CO boiling occurs in the melt. Under this condition the carbon content of the tube does not show an appreciable effect on the deoxidation rate. The oxygen supply by the dissociation of MgO crucible prevents the oxygen content of the melt from decreasing to <20 ppm.

Instrumentation and Control System

Bayesian neural network analysis of fatigue crack growth rate on nickel base superalloys

H.FUJII et al.

The fatigue crack growth rate of nickel base superalloys has been modelled using a neural network model within a Bayesian framework. A 'committee' model was also introduced to increase the accuracy of the predictions. The rate was modelled as a function of some 51 variables, including stress intensity range ΔK, log ΔK, chemical composition, temperature, grain size, heat treatment, frequency, load waveform, atmosphere, R-ratio, the distinction between short crack growth and long crack growth, sample thickness and yield strength. The Bayesian method puts error bars on the predicted value of the rate and allows the significance of each individual factor to be estimated. In addition, it was possible to estimate the isolated effect of particular variables such as the grain size, which cannot in practice be varied independently. This demonstrates the ability of the method to investigate new phenomena in cases where the information cannot be accessed experimentally.

Surface Science and Technology

Effect of phase transformation on stress states in surface layer of laser hardened carbon steel

A.BOKOTA et al.

A model of simulation of laser hardening was presented in the paper. In the model the coupling of thermal field and phase transformations was considered. The thermal field distribution was determined on the basis of diffusion equation with the convection term, the solution of which was obtained by integration of Green's function over the considered region. The fractions of phases created during the phase transformations were calculated by use of TTT-heating diagram and TTT-cooling diagram. The coupled effects of temperature field and phase transformations were considered by applying the additivity principle and Avrami formulae for diffusion transformations while the Koistinen and Marburger empirical formula was used to calculate the martensite transformation. The stresses were determined on the basis of plastic flow model with linear-isotropic material hardening. In the proposed model the constitutive relationships for plane state of strain were modified in the manner of obtaining the zero value of normal force on the axis direction being perpendicular to section under consideration. The changes in thermomechanical parameters of material as a function of phase contents and thermal field were considered in the stress calculations. The problem was solved by finite element method.

Microstructure

The effect of welding process on chi phase precipitation in as-welded 317L weld metals

Y.SONG et al.

Three multipass 317L welds were prepared using submerged arc welding (SAW), flux-cored arc welding (FCAW) and manual metal arc welding (MMA), respectively. A microstructural study was undertaken by trepanning 3 mm discs from specific positions in the weld gap, and examining the thinned specimens by transmission electron microscopy (TEM). It was found that, in addition to Chi phase precipitation detected in the regions where overlapping of the welding passes occurred, the large heat input for each welding pass can also induce Chi phase precipitation during the cooling of the welding pool. The mechanical properties showed that there were few differences resulting from the three processes. The intermetallics which formed due to the high heat input passes did not appear to have a particularly harmful effect on the mechanical properties.

The evolution of precipitates in Nb-Ti microalloyed steels during solidification and post-solidification cooling

C.ZHOU et al.

A series of Nb-Ti steels containing titanium in the range 0.005 to 0.038 wt% and nitrogen in the range 0.005 to 0.011 wt% were prepared using a base composition of 0.06 wt% carbon and 0.027 wt% niobium. Small ingots were cooled slowly in order to simulate larger castings. Cooling was interrupted at various temperatures in the austenite phase field, either by quenching or by holding isothermally before quenching. Transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM) were used to investigate the morphology, distribution, composition, and particle size of carbonitrides in processed ingots. Samples of the quenched ingots were tempered for 1hr at 600℃. Tempered hardness was used to estimate the amount of microalloy elements in solution in austenite at the moment of quenching. Ingots containing 0.013-0.017 wt% Ti were found to be undersaturated with respect to $(Nb_x Ti_{1-x})(C_y N_{1-y})$, and Nb-rich carbonitride precipitates were present after solidification. These were stable during cooling, and supersaturation did not occur until the ingot temperature fell below approximately 1 200℃. It was found that the Nb rich precipitates became Ti rich in the ingots quenched from 1 400℃, when either the nitrogen content was increased from 0.005 to 0.011 wt% or the titanium content was 0.038 wt%. Carbonitride precipitates were not found in ingots containing less than 0.011 wt% Ti for any quench temperature down to 1 000℃, although Nb-rich precipitates were present at 800℃ and in mould-cooled ingots. Holding the ingots isothermally at temperatures down to 950℃ for 3hr brought the composition of precipitates and the concentration of solutes closer to equilibrium. It has concluded that, for the base composition and Ti content less than a critical value of 0.012 wt%, as-cast austenite was more supersaturated with microalloy precipitants than expected from equilibrium considerations. Increasing the Ti content above the critical value led to interdendritic precipitation of carbonitride that precipitated during cooling and reduced the degree of supersaturation.

The role of Mn depletion in intra-granular ferrite transformation in the heat affected zone of welded joints with large heat input in structural steels

H. MABUCHI et al.

Intra-Granular Ferrite (IGF) transformation in the Heat Affected Zone (HAZ) of welded joints has been practically applied in structural steels, but the mechanism of IGF nucleation has not been elucidated yet.

Then, the role of Mn depletion was investigated to elucidate the mechanism of IGF nucleation. It was first demonstrated to prove the direct evidence of Mn depletion at the interface of MnS / ferrite matrix by the nano-probe analysis of Field - Emission Transmission Electron Microscope equipped with Energy Dispersive X-ray Spectroscopy (FE - TEM - EDS). The presence of Mn depletion is also believed to promote IGF nucleation at the interface of MnS newly precipitated on (Mn, Si) oxide, which is considered to have no coherency with ferrite matrix.

Physical and Mechanical Properties

Computation of the diffusional transformation of continuously cooled austenite for predicting the coefficient of thermal expansion in the numerical analysis of thermal stress

I.I. BOYADJIEV et al.

The coefficient of thermal expansion is calculated as a function of the cooling rate, phase composition and temperature. This depends on a numerical method proposed here for computing the phase composition as a function of time and temperature based on the CCT diagram. An exponential equation is used to describe the instantaneous fraction transformed and the parameters in this equation are taken as functions of the transformation start temperature, which in turn is a function of the cooling rate. In the multiphase region, the coefficient of expansion is considered as consisting of two components : thermal and transformational. They are computed from the previously calculated fractions of the participating phases.