Ironmaking and Reduction

Size effect on kinetics of gaseous reduction of iron ore

H.W.KANG et al.

In order to investigate the size effect on the kinetics of the gaseous reduction of iron ore, two kinds of iron oxide pellets of different diameters were reduced with CO-CO_2 gas mixture. Results were analysed using two models, Ishida-Wen's model and the unreacted -core model. From the analysis of the former model, the intraparticle diffusivity through the product layer D_s, the intraparticle diffusivity in the reactant zone D_{so} and the chemical reaction rate constant based on volume k_v were not changed with the particle diameter while Thiele's modulus ϕ and the effectiveness factor E_f were changed. From that of the latter model, the intraparticle diffusivity through the product layer D_e was not varied with the particle diameter, while the interface chemical reaction rate constant k_c was varied. Further investigation revealed that k_c was affected by the diffusion resistance through the product layer, that is, D_s and the particle size as well as the intraparticle diffusivity in the reactant zone and the reactivity.

In-furnace conditions as prerequisites for proper use and design of mud to control blast furnace taphole length

N.TSUCHIYA et al.

Increase in taphole length can be achieved if the taphole mud as injected stay at around the in-furnace taphole opening and sinters there. This can only be possible if the coke column and the mud mass make a good contact at the in-furnace taphole opening.

Theoretical calculation of the penetration depth of the coke column into the hearth showed that the degree of contact of the coke column with the mud mass may change in normal operation of blast furnace.

The degree of the contact can be controlled by controlling the raceway depth of tuyeres above the taphole concerned.

Steelmaking and Refining

Dephosphorization and desulfurization pretreatment of molten iron with CaO-SiO_2-CaF_2-FeO-Na_2O slags

A.HERNÁNDEZ et al.

The present work estimated the ability for the removal of phosphorus and sulfur from hot metal with CaO-SiO_2-CaF_2 fluxes which contain 20 mass% CaF_2 and [mass% CaO/mass% SiO_2] = 4. Silicon losses were also determined along the treatment. Some additions of FeO (4 to 8 mass%) and Na_2O (1 to 6 mass%) were used to change the oxygen potential of the molten iron. The experiments were carried out in an open 10 kg induction furnace using Al_2O_3 refractory in the temperature range 1 350 - 1 400°C.

The oxygen potentials of the melt, continuously measured with a high temperature galvanic cell, were between $10^{-13.4}$ atm (before the treatment) and $10^{-12.0}$ atm (after the treatment). FeO and Na_2O contents in the slag directly affect the oxidation of the alloy elements of the liquid iron. With high silicon contents in the hot metal (0.6%) the maximum removal of silicon was about 80 % whereas the maximum phosphorus and sulfur removal were about 14 and 90 %, respectively. By low silicon contents (0.16 %) the maximum removal of silicon, phosphorus and sulfur were 80, 40 and 95 %, respectively.

A thermodynamic analysis was carried out to predict the final composition of the hot metal and the species that were formed in the slag. Both results, calculated and experimen tal, show that sulfur and silicon were diminished in the melt in a higher extent than phosphorus and manganese. The especies in the slag predicted by the model are in agreement with the X-ray analysis of the slag.

Casting and Solidification

3-dimensional mathematical model for the analysis of continuous beam blank casting using body fitted coordinate system

J.-E.LEE et al.

A 3-dimensional mathematical model has been developed for a fully coupled analysis with fluid flow and heat transfer in the continuously cast beam blank. A body fitted coordinate system was introduced for the complex geometry of the beam blank. This enables the general program to be formulated to analyze the transport phenomena in the arbitrary shaped geometry. The effects of turbulence and natural convection on fluid flow in the strand were incorporated. The temperature distribution and solidification of the strand coupled with the fluid flow were also analyzed. The solidus and liquidus temperatures of the steel were determined with microsegregation model under the given composition of steel. The effects of fluid flow on the heat transfer, the solidification of steel and the development of shell thickness during the casting of the beam blank were simulated at various casting speed.

The recirculating flows appeared in the regions of the web and the flange tip, however, it was not developed between the nozzle and the flange center. The flow normal to the casting direction in the region of the web moved to the upper region of the flange tip near the meniscus. The development of solidifying shell in the center of the flange tip was slowest at the initial stage of the solidification. The development of solidifying shell in the regions of the fillet and the flange center became slow down after the impinging of the inlet flow from the nozzle on the solidifying shell.

Melt instabilities and the effect of surface tension on preventing edge serrations in melt overflow alloy strip casting

A.KALKANLI et al.

Direct casting of metallic strip onto a single rotating chiller is possible by the displacement of liquid metal in a horizontal pouring channel against a vertically moving chiller surface. In the case where of a high liquid/vapour surface tension exists, the liquid can not be dragged out of the melt pool by momentum transfer. The critical surface tension values for making strip in a series of 304 stainless steels as measured by a modified oscillating droplet technique, values 2.1-1.4 Nm^{-1}. Surface tension values greater than these lead strip break-up. Casting of alloys with a low surface tension such as 1.3-1.1 Nm^{-1} at a wheel speed of 2.7 $m.sec^{-1}$ can result instability waves such as Marangoni, Kelvin-Helmholtz and capillary waves. These waves result in the formation of edge serrations in the solidified strip. If the casting speed is sufficiently high to overcome these melt instabilities, strips can be produced with a smooth edge and uniform dimensions. In this paper the results of melt overflow direct strip casting experiments with different alloy and process conditions for strip dimensions up to 700 μm and 40 mm wide are presented.

In-situ observation of engulfment and pushing of nonmetallic inclusions in steel melt by advancing melt/solid interface

H.SHIBATA et al.

Engulfment or pushing of inclusion particle by advancing melt/solid interface of steel has been investigated *in-situ* with a confocal scanning laser microscope. When the velocity of advancing interface exceeds a critical value V_c for a particle with radius R, solid alumina cluster particle or liquid silicate/aluminate globular particle in steel melt is found engulfed by the interface which extends in a convex way to form a bump toward the particle. At lower velocities or for smaller radii, the particles in both classes are pushed by the interface which does not form the bump. For solid alumina clusters, $V_c(\mu m/s) = 60/R(\mu m)$, whereas $V'_c = 23/R$ for the liquid globular particles, although V_c is not much different from V'_c at same R. The shape of the bump is reasonably reproduced by a two-dimensional FEM analysis of heat transfer from the melt across the particle to the interface. Reduced heat transfer caused by the intervening particle is considered responsible for the engulfment at V_c usually encountered in conventional casting process of steel.

Morphological transition of rapidly solidified Al-Cu eutectic ribbons with the variation of cooling capacity of the rotating wheel

S.M.LEE et al.

The effects of the wheel surface condition were investigated on solidification behavior and microstructural evolution of Al-Cu eutectic ribbons. The local solidification velocity was controlled by the wheel surface condition which can be changed by either heating the wheel or coating the wheel surface with boron nitride. The origin of inhomogeneities in the Al-Cu eutectic ribbons both through the ribbon thickness and in the transverse plane was also studied. The average cooling rate of the ribbon during eutectic solidification was greatly changed by more than 1 order under the different wheel conditions. The change of the wheel surface condition brought a variety of changes in eutectic growth morphology. It is evident that the control of the wheel surface condition is significantly important in producing the ribbons with controlled microstructures which will guarantee the reliability of the ribbon materials in practical applications.

Weld formation in microgravity

K.NOGI et al.

In order to investigate the effect of gravity on the formation of weld, gas tungsten arc (GTA) welding was performed both in a microgravity environment and in a terrestrial environment. The microgravity environment was produced for 10 sec with less than 10^{-5} G by a drop-shaft type microgravity system at Japan Microgravity Center (JAMIC). The material used was an aluminum alloy. It has become clear that in the microgravity environment, the weld bead is formed flatly and a large amount of metal can be welded at once and in any welding position though the weld shape is significantly affected by gravity in the terrestrial environment. When helium rather than argon is used as a shielding gas, the butt weld is formed more flatly because the arc pressure is reduced. Judging from the distribution of the grain structures in the weld, in the microgravity environment, the temperature gradient is smaller than that in the terrestrial environment, and the degree of the constitutional supercooling is higher due to the absence of the heat transfer by gravity.

Physical and Mechanical Properties

Tensile instability in a hydrogenated low alloy steel

B.SASMAL et al.

Sheet tensile specimens prepared from a cold rolled low alloy steel were annealed at 700°C to get equiaxed ferrite grains of 8, 21.5 and 32.5 μm diameters other than spheroidal carbides and inclusions, charged cathodically in 1N NaOH and 0.1N H_2SO_4 solutions with a current density of 50 mA/cm^2 and tested in a hard beam tensile testing machine at a slow strain rate. Fracture characteristics were studied in SEM. By comparing the values of σ at the point of intersection of computed σ *vs.* ε and $d\sigma/d\varepsilon$ *vs.* ε curves with the actual values corresponding to UTS a measure of the enhancement of plastic instability by hydrogen was obtained. It has been found that the higher the hydrogen content the lower are the values of stress and strain at which plastic instability was initiated, and the higher the ferrite grain size the greater in the enhancement of this instability. These effects have been discussed in the light of viewed fracture modes.

Work hardening of hypereutectoid steel and eutectoid steel during drawing

S.NISHIDA et al.

Work hardening of pearlite and bainite during drawing of high-carbon steel wires was studied by using stress-strain curves of drawn wires and making a detailed observation of their microstructure. The study revealed the following relationship between flow stress and strain in high-carbon steel wires. Flow stress σ is represented by a weighted average of the strengths of ferrite and cementite. The amount of work hardening $\Delta\sigma$ is represented by an equation corresponding to exp ($B\varepsilon$) where B is a constant that depends on the initial microstructure of the steel wire and ε is the strain. When the initial microstructure of steel wire is made up entirely of a pearlite lamellar structure, the value of B is 0.5. When the initial microstructure contains some bainite, the value of B is lower than 0.5. Finally the flow stress was formulated as a function of carbon content, supercooling degree, and ε. The calculated maximum flow stress showed good correlation with the measured flow stress of 0.8% C and 0.2%Cr-0.92%C steel wires during drawing.

Mathematical modelling of mean flow stress during the hot strip rolling of multiply-alloyed medium carbon steels

A.KIRIHATA et al.

The kinetics of static, dynamic and metadynamic recrystallization applicable to a Cr-Mo-V-Ni-Nb steel were determined by means of torsion testing. A mathematical model for the flow stress was then drawn up based on the Misaka equation, but which incorporates the effects of dynamic, metadynamic, and static recrystallization. In this way, it takes both the accumulated strain as well as microstructural evolution into account. In addition, mill log data obtained from the Wakayama Steel Works of Sumitomo Metal Industries were converted into mean flow stresses (MFS's) using the Sims approach. The operating data obtained in this way are compared with the predictions of the model, and excellent agreement is obtained between the measured and predicted MFS values over the whole range of rolling temperatures and conditions. The predictions indicate that dynamic, followed by metadynamic, recrystallization takes place during finish rolling of this grade.

FEM analysis of ductile crack growth in fracture transition region for steels with defferent void nucleation frequency

H.YOSHIDA et al.

Local stress and strain fields in front of a crack have been computed by FEM analysis using a Gurson model which takes into account void nucleation and growth within the material. The original Gurson model has been revised to fit the actual material by introducing experimentally obtained deformation and fractographic data of the material. Calculation has been applied for the ductile-to-brittle transition regions up to the ductile crack growth stage in two steels with different transition bahaviors. Higher magnitudes of local stress and strain as well as larger extensions have been shown for a steel which has less nucleated void volume fraction, resulting in higher resistance against the ductile crack growth. Local stress increases with lowering test temperature whereas local strain decreases. Insignificant temperature dependence of R-curves has been understood from the calculated J-integral values because of the cancellation of the stress increase and strain decrease. The calculated R-curves have been shown to be consistent with the experimentally observed ones.

The segregation behavior of alloying elements based on the divorced coincident segregation in 5%Ni steels by the application of FE-TEM

H.MABUCHI et al.

The segregation mechanism of alloying elements in prior austenitic grain boundaries of embrittled 5 % Ni steels has been investigated by AES in previous works, while that of improved 5 % Ni steels has not been clarified yet. In the present study, the segregating behavior of alloying elements in the improved 5 % Ni steels has been elucidated for the first time by the application of FE-TEM with an emphasis on the effects of soluble Al on the suppression of temper embrittlement and hydrogen embrittlement.

It is consequently made clear by the application of FE-TEM-EDS that alloying elements tend to segregate coincidently to grain boundaries, occupying the opposite side of grain boundaries each other according to their interactions. The observed behavior is newly defined as the "divorced coincident segregation" in the present study, and is considered to result from the moderate site competitions in the deep potential well of McLean's equilibrium segregation. The results also show that the amount of {Al−(Si+Cr+Mn)} segregated in grain boundaries governs the resistance to the two types of embrittlement in 5% Ni steels under the condition of low impurities such as N, P and Sn.