Fundamentals of High Temperature Processes

Rate of reduction of ferric and ferrous oxide from calcia–silica–alumina slag by carbon in liquid iron

D.E.WOOLEY et al.

Reduction of ferric and ferrous oxide from calcia–silica–alumina slag by carbon in liquid iron has been studied. A base slag (48%CaO–40%SiO_2–12%Al_2O_3) containing iron oxide (less than 16 wt% total iron) was reduced by carbon dissolved in a liquid iron bath (approx. 4 wt% C). The temperature was in the range 1 400–1 600°C. The reaction rate was calculated from measurements of the total inlet gas flow rate and the CO concentration in the outlet gas stream. Slag and metal samples were taken in some experiments. Two observations are reported: the apparent rate constant decreases as the reaction rate decreases; and most ferric oxide (Fe_2O_3) is reduced before any ferrous oxide (FeO) is reduced. The authors conclude that the apparent rate constant is the mass transfer coefficient for ferrous cations in the slag phase, and that the overall reduction rate is determined by the mass transfer rate of ferrous cations when only ferrous oxide remains in the slag (*i.e.* all the ferric oxide has been reduced).

Energy dissipation distribution in gas-stirred liquids

Y.KISHIMOTO et al.

In gas-stirred steel ladles, the agitation of the surface is very important for mixing and chemical reaction. To understand the surface wave propagation, a new ultrasonic method was developed to measure the location of the interface and propagation velocity. From these measurements the energy dissipation in the waves was estimated. In separate calculations, the energy dissipation in the bulk of the liquid was computed, leading to the following conclusions regarding the approximate percentage distribution of the energy dissipation in the various areas in a gas-stirred ladle:

liquid recirculatory zone:	36%
gas–liquid plume zone:	22%
gas–liquid spout zone:	41%
surface wave zone:	<1%

Ironmaking and Reduction

A theoretical investigation of kinetics and mechanisms of iron ore reduction in an ore/coal composite

S.SUN et al.

In this heterogeneous multi-reaction system, kinetic steps in each group of heat transfer, mass transfer and chemical reactions are investigated first to identify the slowest step based on a validated mathematical model of 19 independent equation.[2,3] They are conductive heat transfer, convective mass transfer and carbon gasification by CO_2 and H_2O. The overall reaction of metallization of iron ore by coal with heat supplied by an external source is largely limited by the conduction of heat though the sponge iron shell of an ore/coal composite.

Building of a mathematical model for the reduction of iron ore in ore/coal composites

S.SUN et al.

A non-isothermal and non-isobaric mathematical model which consists of 19 independent equations, was developed for the study of the kinetics of reduction iron ore in an ore/coal composite, based on experimental condition with furnace temperature of 1 200°C and ore/coal ratio of 80/20. This model has been applied to the other three sets of independent experiments different in furnace temperatures (1 300°C) and ore/coal ratios (82/18 and 85/15) for its validation. General agreement between the computed and measured temperatures, the degree of reduction and the degree of carbon gasification as functions of reaction time and location illustrates that this mathematical model is capable of representing data observed in this system.

Steelmaking and Refining

Residence time distribution analysis by the modified combined model for the design of continuous refining vessel

J.-H.ZONG et al.

Flow analyses with RTD experiments have been made for the fundamental design of continuous refining vessels of metallurgical gas injection systems. The modified combined model is suggested for the analysis of various kinds of RTD shapes and it is very effective for the treatment of tail-data. The plug flow fraction τ_p, which is statistically obtained by the present model as a characteristic parameter of the RTD curve, is very much reliable regardless of the cut-off position of data. The effects of various design parameters such as the gas blowing position, the gas flow rate, the divided blowing with multiple lances, the supplementary bottom blowing, and the installation of dams are examined by means of this model for obtaining design concepts of the vessel. The plug flow fraction τ_p could be increased by the cell effect of the divided blowing, the minimization of dead zone by the supplementary bottom blowing, and the proper placement of dams.

Casting and Solidification

Numerical simulation of interface shape around an insoluble particle for Fe–C alloys using a phase-field model

M.ODE et al.

The first trial for numerical simulations of solid/liquid interface shape change around an insoluble particle for Fe–C alloys has been carried out. Real-time interface shape evolution during unidirectional solidification has been calculated using the phase-field model with parameters determined by thin interface limit condition. The interface becomes concave near the particle because of solute enrichment in the liquid between interface and a particle. Liquid trench ahead of the particle and thin liquid film along its surface remain until the late stage of solidification. The results are qualitatively in good agreement with the reported experimental observations. The effects of interface velocity and initial carbon content on the interface shape are also examined. Using the obtained interface shapes, the forces to the particle are estimated and the particle engulfment behavior by interface is discussed.

Influence of wettability on the behavior of argon bubbles and steel flow inside the mold

Z.WANG et al.

It is well known that the occurrence of the defects has a close relation with the behavior of the bubbles and the flow pattern of the molten steel inside the mold. In this research, the behavior of argon gas inside the flowing water and the influence of wettability between the water and the porous refractory through which argon gas is injected were investigated. In addition, the influence of the wettability on the behavior of injected gas in molten iron was investigated experimentally. Furthermore, a water model simulating the submerged entry nozzle and the mold of the continuous casting process was established. The behavior of argon gas that was injected into water flow through a porous refractory in nozzle and its influence on the flow pattern of the water inside the mold were studied in the cases of different wettability between water and the porous refractory. Water model experiment demonstrated quite different behaviors of the bubbles and flow pattern of water when the wettability is changed. The result in the case of poor wettability is thought to be similar to those of the continuous casting process in which molten steel does not wet the refractory.

Analysis and Characterization

Characterization of relieved non-metallic inclusions in stainless steel by image processing of micrographs

M.KAWAKAMI et al.

In the previous work, a new method to identify the shape of an inclusion was developed with the aid of image processing equipment. An attempt has been made to characterize inclusions in stainless steel using the method. Classifying areas for circles, triangles, squares, bars and intricates has been determined more accurately on two dimensional chart of $y=L^2/(4A\pi)$ and $x=\pi D^2/(4A)$. The inclusions were relieved on the surface of specimen by electrolytic etching with the SPEED technique. By these improvements, the inclusions with triangular, square, bar and intricate shape, as well as circular inclusions, were clearly classified. However, it seemed difficult to identify the chemical species of inclusion from its shape in the case of specimen from molten steel and CC slab. In the case of rolled sheet, the inclusions with different shape could be identified respectively. Therefore, the image processing of inclusions coupled with relieving of them by electrolytic etching might be one of the hopeful ways to characterize the inclusions in rolled sheet of stainless steel.

Forming Processing and Construction

Incremental formulation for the prediction of microstructural change in multi-pass hot forming

J.YANAGIMOTO et al.

A new mathematical formulation for static microstructural changes in hot forming is proposed. This formulation can be easily coupled with incremental model for dynamic microstructural changes as it is formulated in an incremental form using the dislocation density as a representative variable with the simplification of recrystallized structure. Coupling incremental formulations for dynamic and static microstructural changes, microstructural changes under multi-pass hot forming are computed and discussed. As these formulations are formulated in an incremental form, we will be able to predict microstructural evolution including partial dynamic/static recrystallization caused by any deformation history and temperature history computed by FEM and/or FDM.

Microstructure

Ultra grain refining and decomposition of oxide during super-heavy deformation of oxide dispersed ferritic stainless steel powder

Y.KIMURA et al.

Mechanical milling using a high energy planetary ball mill was applied to the powder mixtures of iron, chromium and yttria (Y_2O_3) (Fe–24mass%Cr–0–15mass%Y_2O_3) to introduce a very large strain into the iron-base matrix, and microstructural changes during mechanical milling were investigated in relation to decomposition behavior of Y_2O_3 particles. Mechanical milling of more than 36 ks was long enough to allow the mechanical alloying of iron and chromium powders. After the milling of 36 ks, ultrafine bcc crystalline grains of 10 to 20 nm were formed within the Fe–24mass%Cr–15mass%Y_2O_3 powder mixture and 15 mass% of Y_2O_3 particles were almost decomposed. The resultant powder mixture markedly hardened to about 1 000 Hv. The decomposition of Y_2O_3 particles can be explained as being due to the formation of an amorphous grain boundary layer where yttrium and oxygen atoms are enriched. As a result, it is proposed that, for the dissolution of Y_2O_3, bcc crystalline grains should be refined to a nanometric size to provide a sufficient volume fraction of the grain boundary layer, and that Y_2O_3 particles should be crushed to several nanometers to produce the driving force for the decomposition of Y_2O_3 particles.

Effect of nitrogen on martensite-austenite constituent in low carbon steels

M.P.STAIGER et al.

The effect of dissolved nitrogen on phase transformations and microstructural evolution in low-carbon high manganese silicon steel wire-rod was examined for varying nitrogen levels of 30, 70, and 100 ppm, while keeping the base composition constant. It was found that nitrogen suppresses the pearlite reaction start temperature by up to 30°C. A strong correlation was discovered between the nitrogen level and the formation of martensite–austenite microconstituent (MA phase). The possible mechanisms by which nitrogen causes the formation of MA phase are discussed. The main conclusion drawn from this study is that levels of nitrogen between 70 and 110 ppm can have a significant effect on microstructure, such that up to approximately 10 vol% of MA phase is formed in these steels. Microstructural changes in titanium-microalloyed steels were also investigated—particularly changes in the development of the MA and pearlite phases. The pearlite content was up to double that found in a Ti-free alloy. Microalloying with titanium was found to be effective in completely eliminating MA phase.

Physical and Mechanical Properties

Effect of R phase formation on the impact toughness of a 25%Cr–7%Ni–3%Mo duplex stainless steel

Y.SHIMOIDE et al.

The aging behavior (microstructural evolution and mechanical properties change) of a 25%Cr–7%Ni–3%Mo duplex stainless steel at 873 K was investigated. A very short term (3.6 ks) aging treatment caused a significant decrease of impact toughness before the formation of σ phase. Quasi-stable R phase was observed to form locally in the material aged for 3.6 ks. These results indicate that the significant loss of impact toughness due to the R phase formation at the very early stage of aging occurs before the embrittlement due to the σ phase.

Effects of surface condition on room temperature tensile properties of cast TiAl–Fe–V–B alloy

S.NISHIKIORI et al.

Ti–48.0Al–1.3Fe–1.1V–0.30B(mol%) has been developed to improve creep properties.[1] In order for this alloy to be widely employed in structural materials, it is important to understand effects of the surface finishing on mechanical properties. The finishing, such as the turning, the grinding, the beltgrinding (defined as the grinding using the endless buff-belt) of this alloy was carried out under the production scale in this study. The effects of machined surface condition on room temperature tensile properties of this alloy were investigated with metallographic characterization. The room temperature ductility was influenced by surface condition and was within the range from about 0.5% to about 1.3%. As a result, the improvement of ductility was attributable to removal of grain distortion at subsurface. Moreover, compared to the results of various machined specimens, the effects of chemicalmilled surface on room temperature tensile properties were also investigated.

Effect of partial solution treatment on toughness of 12%Cr–0.3%C steels

T.TSUCHIYAMA et al.

In 12%Cr–0.3%C martensitic steels, the effect of partial solution (PS) treatment in the (γ+carbide) two phase region was investigated in terms of the relation between microstructure and impact toughness. PS treatment is very effective for refining γ grains, because insoluble carbide particles works as obstacles to grain growth. The γ grain refining results in a significant lowering of Ductile–Brittle Transition Temperature (DBTT). This is mainly due to the reduction of grain boundary stress concentration which is caused by pile-up of dislocations to grain boundary. Besides, PS treatment contributes to homogeneous dispersion of carbide particles: In specimens with full solution (FS) treatment, carbide particles precipitate along lath boundary of martensite during tempering, and this causes early crack initiation in impact testing. On the other hand, in specimens with PS treatment, carbides preferentially precipitate on insoluble carbide particles which have homogeneously dispersed within the martensite matrix. This results in an increase of upper shelf energy in impact testing. It was also found that PS treatment suppresses precipitation of grain boundary carbide which occurs during slow cooling from γ phase region, because the insoluble carbide particles provide preferential precipitation site within γ grains. As a result, DBTT is not dependent on cooling rate in PS treated specimens, although it is greatly raised in FS treated specimens with slow cooling because of the grain boundary precipitation of carbide.