Fundamentals of High Temperature Processes

Non-linear kinetic analysis of decarburization and deoxidization of liquid iron by Ar–CO–CO_2 gas mixtures

X.TAO et al.

Decarburization and deoxidization of liquid iron in Ar–CO–CO_2 gas mixtures were investigated at 1 843 K using a cold crucible. The carbon or oxygen concentration decreased against their chemical potential gradients in the initial stage of the reactions. The concentration changes in the whole process were successfully reproduced by nonlinear equations based upon the two independent reactions in which the nonlinear reaction CO(g)=C+O was included. It has been shown that the decarburization of liquid iron in Ar–CO–CO_2 under reduced pressure can be also reasonably described by the nonlinear kinetic equations.

A capacitance probe for measurement of bubbles in molten metals

Q.FU et al.

A probe has been developed for measuring bubble size, velocity and frequency in molten metals. The probe has been tested on a low melting point alloy (Belmont alloy) and on aluminum. Bubble signals are discernible in either metal. The probe measures the change in capacitance between a wire and the metal as a bubble passes. Because there is no electrical contact necessary between the wire and the metal, the wire may be sheathed with a material (*e.g.* alumina) that is inert to the metal. The ruggedness of this design was demonstrated by its use for three hours in aluminum. A bridge circuit which can measure the small capacitance change was devised and a deconvolution procedure has been developed whereby bubble size distributions can be obtained. Measurements have been made of the bubble size and velocity above J-shaped nozzles through which argon was injected. Similar measurements have been made of the bubble size distribution above a porous alumina plug and the bubbles were larger than those observed in water at a comparable flowrate.

Ironmaking and Reduction

A development of computer model for simulating the transport phenomena in COREX melter-gasifier

S.C.LEE et al.

The compuer model, which could simulate the transport phenomena of the COREX melter-gasifier considering the pyrolysis behavior of raw coal, was developed. This model was made up of 192 ordinary differential equations for gas and solid phases in the 1-dimensional fixed bed part and balance equations for gas phase in the combustion zone and the freeboard zone of 0-dimensional assumption. This coupled non-linear equations are calculated by the LSODE packages and Gibbs free energy minimization method. The effluent gas temperature showed good agreement with the operational data. The temperature of the gas was decreased linearly with the distance from the combustion zone. The predicted melting position of ore and flux mixture was 2.0 m high from the combustion zone. CO was mainly generated in the combustion zone and H_2 was mainly produced during the devolatilization of coal. The fixed bed in the melter-gasifier could be divided into four distinct zones. Each zone has its own reaction characteristics such as heating zone, primary pyrolysis zone, secondary pyrolysis zone and gasification zone.

Casting and Solidification

Forming of positive macrosegregations during steel ingot solidification

Ž.RADOVIĆ et al.

It is known that the degree of positive segregations in upper part of ingots is very sensitively dependent upon the enriched liquid velocity. In this paper, relationship between chemical composition of steel and liquid density changes are considered. Besides, the influence of the primary and secondary arm spacing (λ_1, λ_2) on the liquid flow velocity, *i.e.* intensity of positive macrosegregations, was studied, using examples from 3-tone ingots, for different grades of steel. The elements as W, Ni, Mo, Cr, decreases the effect of density changes ($d\rho_L/df_L$), *i.e.* they have smaller tendency to segregation forming. Global intensity of positive macrosegregations, S_j^g, which can be calculated by integration of local macrosegregations degree, depends approximately linearly on the liquid flow velocity.

Large scale simulation of dendritic growth in pure undercooled melt by phase-field model

S.G.KIM et al.

In this study we presented a double-grid method for efficient computation of complex dendritic pattern evolving in a large scale solidifying system of pure undercooled melt. The method, which is based on the large difference in phase-field diffusivity and thermal diffusivity in pure material, enables us to use a large time step. The phase field was calculated adaptively only on the grids within the interfacial region and also the thermal field was calculated only within the thermal boundary layer. The computation showed that the complex dendritic patterns with well-developed tertiary arms can be obtained even in a personal computer with a moderate memory space. The computational efficiency of this method, the competitive growth and coarsening of the secondary arms and the tertiary branching from secondary arms were discussed.

Effect of solidification rate and temperature gradient on the changes of mushy zone length in Pb–36mass%Sn binary alloys during upward directional solidification

M.LI et al.

Upward directional solidification experiments have been carried out on Pb–36mass%Sn binary alloys with varying the solidification rate and temperature gradient. Results show that due to solute convection, the length of the mushy zone was not constant even when the dendritic growth at a constant temperature gradient was maintained during upward directional solidification. The length of the mushy zone decreased with increasing fraction solidified if solute convection occured. At a constant solidification rate, the greater the temperature gradient is, the greater the change of length of mushy zone is. At a constant temperature gradient, the smaller the solidification rate is, the greater the change in length of the mushy zone is. Effect of solute convection on the length of the mushy zone during upward directional solidification is responsible for the composition change of Sn at ahead of the mushy zone. If the composition at ahead of the mushy zone changes greatly as increasing the fraction solidified, the change of length of the mushy zone is greater.

Analysis and Characterization

Evaluation of heterogeneity in thickness of passive films on pure iron by scanning electrochemical microscopy

K.FUSHIMI et al.

Scanning electrochemical microscopy (SECM) was applied to evaluate the heterogeneity of a passive film formed on a pure iron electrode in deaerated pH 8.4 borate solution. A probe current image of SECM was measured with a tip-generation/substrate-collection (TG/SC) mode in deaerated pH 8.4 borate solution containing 0.03 mol dm^{-3} $Fe(CN)_6^{4-}$ as a mediator. The difference in thickness of passive films formed on two iron plates at different potentials could be evaluated from the probe current image. The probe current image of the passivated iron surface with distinctive crystal grains was composed of the patch patterns, the shapes of which coincided completely with the shapes of the substrate crystal grains. The probe current flowed above the grain surface oriented to {100} plane was less than that above the grain surface oriented to {110} or {111} plane. The grain orientation dependence of probe current was ascribed to the difference in thickness of passive films formed on the crystal grains.

Physical and Mechanical Properties

Development of a three-dimensional model for ductile fracture in materials containing two types of microvoids

H.QIU et al.

There are three stages in ductile fracture process: voids initiation, void growth and void coalescence. In the final stage, ductile fracture occurs due to the void coalescence. Thomason suggested that voids begin to coalesce when a plastic limit-load condition is fulfilled for localized plastic failure of the inter-void matrix. On the basis of this critical void-coalescence condition, we developed a three-dimensional model for ductile fracture considering two types of voids with different sizes, and applied this model to a SA440 steel with and without pre-straining. With the critical strength of particle/matrix interface and the theoretical void growth strain obtained from the

model, the reason for the decrease in fracture strain caused by plastic pre-strain was discussed.

Evaluation of ductile fracture of structural steels by microvoid model

H.QIU et al.

In the present work, the ductile fracture of structural steels and the effect of plastic pre-strain on ductility have been investigated by tensile testing. The fracture process consisting of void nucleation, growth and coalescence was observed by scanning electron microscopy (SEM). The nucleation strain of microvoid was measured experimentally. The critical interfacial strength of particle/matrix interface was calculated by dislocation model and continuum analysis, and the void growth was evaluated by Rice–Tracey model. It was found that longitudinal void coalescence does not affect fracture even though large cracks exist, but particle position affects void nucleation. Thomason's plastic limit-load model was used to predict void growth strain. Through the analysis of ductile fracture process, the influence of plastic pre-strain on ductility was discussed.

Acoustic emission behavior during tensile tests of low carbon steel welds

C.S.LEE et al.

The tensile behavior of a low-carbon low alloy steel has been studied by means of acoustic emission (AE) technique for the welded joint consisting of three regions (the base metal, the heat affected zone (HAZ) and the weld metal). The AE characteristics of the base metal are distinctly different from those of the HAZ and the weld metal. For the base metal with a ferrite–pearlite microstructure, most of the AE events occur around the yield point, mainly due to the dislocation movements associated with the tensile deformation. For the HAZ and the weld metal, a second AE peak with higher energy is evident after yielding, in addition to the AE peak occurring around the yield point. The second AE peak is attributed to the presence of martensite, as examined by the AE results obtained from the base metal heat-treated to have different martensite volume fractions. The ferrite–martensite interfacial debonding and/or the martensitic plate cracking act as the principal sources of the second AE peak, as confirmed by the microstructural observations and the frequency spectrum analyses.

Effect of ferrite grain size on tensile behaviour of a hydrogenated low alloy steel

S.K.SINGH et al.

A low alloy steel containing 0.10C, 0.25Si, 0.87Mn, 0.56Cr, 0.47Ni, 0.21Mo, 0.023S and 0.01P (mass%) was reduced by cold rolling to 1.6 mm in thickness and recrystallised at 700°C for 24, 72 and 120 h to get ferrite grains of 8, 21.5 and 32.5 μm respectively along with a random distribution of some spheroidal carbide particles and a few inclusions. Tensile specimens prepared from these sheets were cathodically charged in 1 N NaOH, 0.1 N H_2SO_4 and 1.4 N H_2SO_4 solutions for periods varying from 2 to 24 h, with the current density of 50 mA/cm^2. Tensile tests were carried out with the cross-head velocity of 1.2 mm/min and fracture surfaces were examined in SEM.

It has been found that not only the charging time in an electrolyte but also the electrolyte itself exert influences on the tensile properties and fracture characteristics of the steel. Increase in ferrite grain size has enhanced toughening as well as embrittling (beyond a certain limit of hydrogen content) of the steel under the charging conditions, and no remarkable damage effect of hydrogen has ever been noted at grain boundaries. Influence of ferrite grain size on tensile properties and fracture characteristics appears to be due to the change in hydrogen concentration inside the grains as the grain boundary area per unit volume changes with grain size since the hydrogen trap density at grain boundaries follows a certain ratio to the hydrogen concentration inside grains.

Charging with 1.4 N H_2SO_4 solution embrittles the steel even with a low hydrogen content by causing an irreversible damage and ferrite grain size seems to have little effect on this.

Stress and temperature dependence of time to rupture of heat resisting steels

M.TAMURA et al.

A new relation among the time to creep rupture, the stress and the temperature has been developed. Assuming the velocity of dislocations is controlled by a thermally activated process, the time to rupture, tr is expressed as

$$\log t_r = \frac{Q - V\sigma}{2.3RT} - C,$$

where Q, V, σ, R, T, C are respectively the activation energy, the activation volume, the applied stress, the gas constant, the absolute temperature and the Larson–Miller constant, *i.e.* about 20. The new equation reads that the applied stress in a linear scale is a linear function of the Larson-Miller parameter, $P = T(\log t_r + C)$.

The new relation has been applied to the long term rupture data of several heat resisting steels obtained by National Research Institute for Metals. According to the equation the rupture data for each material can be classified into 2–4 groups where the deformation mechanism differs with each other. It has been found that for each group the data are excellently fitted to the equation.

A set of the data from several hours to longer than 100 000 h are roughly well fitted to another expression of a hyperbolic tangent type. The expression is the approximate equation of the above theoretical expression.

Social and Environmental Engineering

Electrical properties and melting treatment rate of a continuous induction waste melter

T.MATSUO et al.

The continuous induction melter with a graphite-packed bed heat generator has a possible application to a waste melter because of its flexibility regarding waste contents, large treatment rate, and safe performance. This study proposed an analysis scheme for locally matching conditions between a melter and a high frequency electric power generator, and for fluctuation ranges of the frequency and input electric power in the melter. This scheme consisted of estimations of the melter coil inductance and resistance by eddy current loss from analytical solutions of Maxwell equations, which are linked to the locally matching conditions about capacitance and transformer turn number ratio. The measured results in a 100 kW pilot melter were compared to experimental ones. Energy use efficiency of the melter was also obtained by carrying out melting treatment rate measurements regarding two major components included in the wastes, iron and calcium silicate.

Numerical results agreed well with the measured ones regarding the local matching conditions (capacitance: 10.4 μF, transformer turn number ratio: 7/16), and the fluctuation widths of the frequency (0.3 kHz) and input power (7%). The measured melting treatment rates were 135 kg/h for iron and 40 kg/h for calcium silicate, when the respective values of input electric power were 92 and 85 kW. Based on these results, the energy use efficiency of the pilot melter was about 40%.