Fundamentals of High Temperature Processes

Mathematical model of simultaneous slag-metal reactions in multi-components system

Wu P.

A mathematical model describing the simultaneous reactions in multi components system, such as hot metal pretreatment in which bulk flow from the bulk to the slag metal interface occurs, is proposed in order to exactly evaluate the mass transfer in the boundary films resulting from diffusion and that from bulk flow, respectively. This model, furthermore, allows accurate estimation of interfacial concentrations and of chemical reactions at interface.

The model is applied to the experimental data reported in literatures considering the mass transfer in slag phase, that of in metal phase, and chemical reaction at slag metal interface as the rate controlling steps. The determined kinetic parameters in this model lead to the following conclusions;

(1) To describe the decarburization rate, it is necessary to take the retarding phenomena at high interfacial oxygen partial pressure into consideration.

(2) The chemical reaction resistance of silicon reaction should be considered.

(3) The stirring of the bath by bottom blowing gas tends to accelerate the mass transfer in the metal phase more than that of the slag phase, compared with that by mechanically rotated rod.

"*In-situ*" observation of collision, agglomeration and cluster formation of alumina inclusion particles on steel melts

H. YIN et al.

A long-range strong attraction between alumina and alumina-rich solid inclusion particles, and detailed sequence of the collision, agglomeration and formation of alumina clusters have been observed first time "*in-situ*" on molten steel surface by using a confocal scanning laser microscope combined with an infrared image furnace. This attraction force has been found to be over 10^{-16}N, reach over 10 μm for alumina particles larger than 3 μm, and play an important role to promote collision between the particles to form intermediate aggregates, the same between the intermediate aggregates to form loose alumina clusters, and to densify the loose clusters into compact ones. The origin of this long-range strong attraction has been examined to be caused by capillary effect around alumina particles on molten steel surface. Interfacial phenomena at three-phase interface of inert gas-alumina-molten steel is also discussed. In industrial practice, the capillary attraction between the fine alumina inclusions can improve the collision, agglomeration and cluster formation at gas bubble/liquid steel interface when gas injection/bubbling is utilized for refining steels.

Characteristics of agglomeration of various inclusion particles on molten steel surface

H. YIN et al.

The behavior of various inclusion particles at inert gas/molten steel interface was "*in-situ*" studied with a confocal scanning laser microscope. Solid $CaO-Al_2O_3$ and solid $CaO-Al_2O_3-SiO_2$ inclusion particles were subjected to quick agglomeration to form clusters which densified and deformed later. Capillary attraction was found responsible for the agglomeration and densification. The capillary effect also operated between solid $CaO-Al_2O_3$ and liquid $CaO-Al_2O_3$ inclusion particle pairs, making the densification and deformation of the solid inclusion particles much easier. The attraction force was found to be in the range of $10^{-16}\sim10^{-13}$ N for different particles and extended to a distance of up to 100 μm.

However, such capillary attraction was not at all found between liquid $CaO-Al_2O_3-SiO_2$ inclusion particles. Even when the two liquid particles came in touch, merger took place only after contacting for a while. The merger of liquid $CaO-Al_2O_3$ particles was even more difficult for small particles of less than 7 μm, but easier for particles larger than 24 μm. These phenomena are discussed in terms of inert gas/oxide inclusions/liquid steel three-phase interfacial interaction.

Activities of FeO in $CaO-Al_2O_3-SiO_2-FeO$ and $CaO-Al_2O_3-CaF_2-FeO$ Slags

Y. TANIGUCHI et al.

Activity coefficients of FeO in molten $CaO-Al_2O_3-SiO_2-FeO$(< 5 %) slags were determined at 1 673 and 1 873 K by equilibrating the slags with copper-iron alloys in a controlled oxygen partial pressure ($P_{O_2}=5.71\times10^{-12}$ atm at 1 673 K, 1.90×10^{-10} atm at 1 873 K). Activity coefficients of iron in copper-iron (< 4 %) alloys at 1 673 K were preliminarily determined by controlling the activity of iron using $FeO\cdot Cr_2O_3$ saturated with Cr_2O_3 in a various oxygen partial pressures ($P_{O_2}=3.66\times10^{-12}\sim9.14\times10^{-11}$atm).

It was found that the activity coefficients of FeO obey Henry's law, and have the maximum value when the ratio of N_{CaO}/N_{SiO_2} is about 2 at a constant Al_2O_3 content. The activity coefficients of iron in copper-iron alloy referred to pure liquid were determined as

$$\ln\gamma_{Fe}=2.76-11.3N_{Fe}.$$

The effect of a CaF_2 addition to the $CaO-Al_2O_3-FeO$ system on the activity coefficient of FeO was also investigated at 1 723 K.

Non-contact generation of compression waves in a liquid metal by imposing a high frequency electromagnetic field

S. AMANO et al.

In order to confirm the fact that compression waves can be generated in an electrically conductive liquid by using an electromagnetic field, pressure oscillations in a liquid gallium were directly measured under the imposition of a high frequency magnetic field and a mathematical model based on the electromagnetic field theory and the compressible fluid dynamics has been developed. The pressure oscillation with the double frequency of the imposed magnetic field was not only isotropic but also in proportion to the square of the intensity of the magnetic field. These observations coincide with the prediction derived from the mathematical model. Furthermore, the measured distribution of the pressure oscillation in a liquid gallium agrees well with the result of the mathematical model.

Ironmaking and Reduction

Conversion of hematite to iron carbides by gas phase carbidization

A. N. CONEJO et al.

The intrinsic conversion rates of hematite (Fe_2O_3) to carbide (primarily cementite) with a $CO-H_2$ feed-gas have been measured in the temperature range 550 to 650°C, by employing a micro-thermogravimetric system. As a preliminary analysis phase stability diagrams were developed in a triangular representation to overcome limitations of binary-type diagrams already available in the open literature. In general the reaction sequence was identified as consisting of a high-rate conversion of Fe_2O_3 to Fe(33-75 %·min^{-1}) followed by conversion of Fe to Fe_3C. Two stages of carbidization were identified. For the first stage, the conversion rates were higher, from 55 to 75 %·min^{-1}, depending on the reactor temperature. The rate of carbidization in the second stage region was lower, in the range of 25 to 35 %·min^{-1}. The rate of carbidization was found to increase as temperatures decreases, within the range from 600 to 640°C. A model based on adsorption kinetics was developed which qualitatively describes the behavior observed. After conversion of Fe to Fe_3C carbon deposition (sooting) was evident. The catalytic role of cementite (in contrast to Fe) in the heterogeneous sooting-reaction has also been addressed.

Development of shaft-type scrap melting process characterized by massive coal and plastics injection

T. ARIYAMA et al.

A shaft-type scrap melting process in which a large amount of pulverized coal and waste plastics are used as a heat source has been newly proposed. To confirm the characteristics of this process, an experimental furnace with 2 m^3 inner volume was continuously operated. The main results are as follows:

(1) Pulverized coal and plastics could be effectively used to melt steel scrap, and a newly designed oxygen burner enabled mas-

sive injection of such fuels.

(2) Combustion efficiency of coarse plastics was higher than pulverized coal due to its accumulation effect in the raceway. Hydrogen chloride during polyvinylchloride injection was about 5 ppm in the gas cleaning system.

(3) Top charge of plastics generated tar derived from decomposition of plastics in the shaft with low temperature.

(4) Zinc charged with scrap was carried over as zinc oxide with dust in the upward gas, and no adhesion was recognized within the furnace.

(5) Maximum productivity was estimated to be 14 t/dm³ from the viewpoints of flooding and melting rate of scrap.

On the basis of the above operation results of the experimental furnace, the operating condition of the commercial process was investigated.

Analysis and Characterization

On-line determination of manganese in molten steel by atomic apsorption spectrometric measurement of evaporated fine dust at the converter

Y.ISHIBASHI

An on-line determination by an atomic absorption spectrometric method was developed to indirectly determine manganese in molten steel. Particles under 10 μm contained in the fine dust generated from molten steel were directly introduced into an air-acetylene flame, and the atomic absorption signal of manganese in the flame was determined. It was found that manganese was selectively evaporated from the molten steel to yield a manganese - enriched dust. However, the amount of manganese in the fine dust (<10 μm) reflected the manganese content in the molten steel. The evaporation ratio of manganese to iron was dependent on the evaporation temperature. The manganese contents in molten steel could be estimated using the manganese to iron evaporation mass ratio at a constant evaporation temperature. The concentration of manganese in the molten steel has a linear relationship with the atomic absorption signal-ratio of manganese to iron determined in the fine particle dust at the end of blowing.

Microstructure

Microstructure and mechanical properties of SiC reinforced AlN/Al composites

B.S.S.DANIEL et al.

Interconnected network of AlN/Al composites are produced by *in situ* liquid metal-gas reactions. In this study, various Al-Si-Mg alloys are nitrided in N_2-4 %H_2 atmosphere to understand the composite growth mechanism. Both fibre and particulate SiC reinforcements are infiltrated with AlN/Al reaction product to form near dense composites and mechanical properties are compared with those of AlN particulate reinforced AlN/Al composite. The composite microstructure is found to be sensitive to the processing temperature, alloy composition and filler material size and chemistry. The variation in mechanical property is also dependent on the residual porosity. Formation of moisture sensitive Al_4C_3 in SiC reinforced composites causes deterioration of mechanical properties. Various alternatives to prevent Al_4C_3 formation are discussed in the text.

Comparison between static and metadynamic recrystallization -an application to the hot rolling of steels

W.P.SUN et al.

An investigation has been performed to simulate the microstructural evolution during the hot strip rolling of steels. During this research, the controlling softening and recrystallization mechanisms after the hot deformation of austenite were first determined using single-hit and double-hit compression techniques. Based on the experimental flow and softening data, several mathematical expressions have been proposed to quantify the boundary conditions and overall kinetics for static and metadynamic recrystallization, respectively. The static model is expressed as a function of initial grain size, strain, strain rate and temperature, while the metadynamic one only depends on the strain rate and temperature. Together with industrial mill processing parameters, these models were incorporated into an integrative analysis of the hot rolling of plain carbon steel strips. The simulation results indicate that metadynamic recrystallization is dominant and leads to the full softening during rough rolling, where processing temperatures are high and strain rates relatively low. Metadynamic recrystallization can also occur between the initial finishing stands, when larger reductions are applied to the steel band. In general, however, static recrystallization becomes more and more important in the finishing mill. Partial static recrystallization may take place in the later stages of finish rolling, which can be attributed to the decreasing processing temperatures, reduced stand strains and much shorter interstand times. The evolution of the austenite microstructure during hot rolling can be characterized by the grain refinement associated with recrystallization and the subsequent grain growth. Although grain growth is significant during rough rolling, grain refinement with minimum interstand grain growth plays a key role during finish rolling.

Textural changes through grain growth in Ti-bearing IF-steel investigated by orientation imaging microscopy and X-ray diffraction

I.SAMAJDAR et al.

Textural changes were investigated using X-ray diffraction and orientation imaging microscopy (OIM). During normal grain growth, slight increase in γ-fibre (ND // <111>) was observed. Prolonged annealing and a resultant abnormal grain growth, however, decreased γ and increased α (RD // <110>). The decrease/increase in fibres were mainly caused by corresponding changes in F [{111}<112>] and I [{112}<110>]orientations, while E [{111}<110>]and H [{001}<110>]components did not change signif icantly. OIM characterization of grain boundary nature indicated an approximate increase in the fraction of low angle ($<20°$) boundaries with increasing annealing time. At the initiation of abnormal grain growth, the fraction of low angle boundaries (specially those with 1-5° misorientation) were observed to have reached a relatively large value. Such observations may fit well with a simple scheme: the transient strengthening in γ-fibre was possibly caused by normal grain growth of γ-grains. At the later stages of grain growth, the growth of the γ-grains was possibly inhibited/stopped by grains of similar orientations. This, in turn, may increase the fraction of low angle boundaries. When the fraction of low-angle/low-mobility boundaries reached a critical value, growth of certain grains (as F/E in our case) were inhibited/pinned, while few of the more favourable placed/oriented grains could grow abnormally. Measured values of 'free length', defined as the average distance between an i (where i may be F/E/I/H) and a j (where j is less than 20° misoriented with i) grain, showed the highest value for I and the lowest for F. Free length can be considered as an average distance for non-interrupted growth. Highest free length values for I, caused by the spatial locations, possibly favored abnormal grain growth of I grains.

Physical and Mechanical Properties

Strain rate dependence of stress-strain curves in a Ti-Fe-O alloy

H.MORIYA et al.

Quantitative expression of stress-strain curve including strain rate dependence in a Ti-Fe-O alloy was studied at temperatures between 77 and 293 K.

In order to evaluate the strain-rate-independent component, in the first place, the authors endeavored to obtain the stress-strain curve as the curve at 0 strain rate through relaxation tests under constant crosshead displacement. The relaxation-saturated stress-strain points made a single curve. The authors named this single curve as "Base Curve". The Base Curve

was good fitted to the Swift's equation in the following form: $\sigma_{Base}(\varepsilon)=A(\varepsilon+b)^n$, where $\sigma_{Base}(\varepsilon)$ is the stress on the Base Curve, ε the plastic strain, n the exponent, and A and b are coefficients.

The stress-strain curves at the strain rate between 2.8×10^{-5} and 3.0×10^{-2} s^{-1} were paral lel to the Base Curve. Namely, the strain-rate-dependent component, σ^*, was independent of strain at a constant strain rate. The relation between σ^* and strain rate, γ, was expressed in the following form: $\sigma^*=B\gamma^m$, where B coefficient and m exponent.

Finally, the equation, $\sigma=A(\varepsilon+b)^n+B\gamma^m$, is derived for the expression of flow stress-plastic strain relation under the deformation at a constant strain rate.

Damping capacity in Fe-Mn binary alloys

Y.-K. LEE et al.

The damping capacities of Fe-Mn binary alloys have been investigated in a wide range of manganese content from 5 to 30 wt%. The damping capacity increases with increasing manganese content, attains a maximum at approximately 17 wt% Mn, and decreases with further manganese content. It is suggested that the damping mechanisms of Fe-Mn alloys containing γ and ε phases are the stress-induced movement of the defects: stacking fault boundary in γ, stacking fault boundary in ε, ε martensite variant boundary, γ/ε interphase boundary. The appearance of the maximum damping capacity at around 17 wt% Mn in Fe-Mn binary system is well explained with the damping mechanisms. The contributions of the damping mechanisms to the overall damping capacities of Fe-17wt%Mn and Fe-21 wt%Mn alloys are quantitatively analyzed, which indicates that ε martensite bears the major part of their damping capacities.

Social and Environmental Engineering

Rate of methane-steam reforming reaction on the surface of molten BF slag -for heat recovery from molten slag by using a chemical reaction

E. KASAI et al.

A new concept for heat recovery from mol ten slag has been proposed. It involves exchanging energy between sensible heat of slag and chemical energy of gas mixture through methane-steam reforming and its reverse reactions. The validity of this concept was fundamentally verified by obtaining kinetic data on the reforming reaction using molten blast furnace slag samples. This includes essential information such as temperature dependence and effects of composition of reactant gas on the chemical reaction rate. The sulfur containing in slag is also found to play a significant role in the reforming reaction.