Fundamentals of High Temperature Processes

Activities of chromium in molten Fe–Cr–C alloy

J.-H.PARK et al.

The activity of chromium in molten Fe–Cr–C alloy was measured at 1 823 K using chemical equilibration technique in the dilute Cr concentration region. It was found that chromium in Fe–Cr–C alloy showed Henrian behavior up to 3 mass% Cr and that the activity coefficient of chromium at infinitely dilute solution in Fe–Cr alloy was 3.90 at 1 823 K.

The effects of carbon on the activity coefficient of chromium at infinitely dilute solution in Fe–Cr–C alloy could be expressed as follows;

$$\ln \gamma^{\circ}_{Cr(S)} = 1.29 - 7.09 X_C \quad \text{at } 1\,823\,K$$

There is little temperature dependence of the activity of chromium at carbon saturated condition.

The standard Gibbs energy of mixing for Fe–Cr alloy and Fe–Cr–C_{satd} alloy was calculated using the Gibbs–Duhem relationship. The results indicated that the affinity between chromium is larger than that of chromium for iron in Fe–Cr alloy. But the affinity between chromium and carbon is increased with increasing carbon.

Activity of $AlO_{1.5}$ for the CaO–$AlO_{1.5}$–$CeO_{1.5}$ system at 1 773 K

S.UEDA et al.

The isothermal phase relations for the CaO–$AlO_{1.5}$–$CeO_{1.5}$ system have been investigated at 1 773 K by a chemical equilibration technique. Activity of $AlO_{1.5}$ in this system was also measured by equilibrating molten Cu and the CaO–$AlO_{1.5}$–$CeO_{1.5}$ flux under a controlled oxygen partial pressure. The activity coefficient of Al at infinite dilution in molten Cu was determined at 1 773 K. Iso-activity curves of $AlO_{1.5}$ for the CaO–$AlO_{1.5}$–$CeO_{1.5}$ system are drawn from the experimental results. The addition of $CeO_{1.5}$ to the CaO–$AlO_{1.5}$ system was found to decrease the activity coefficient of $AlO_{1.5}$ in the melts. The effect of Ce addition to Al-killed steel was also discussed using the present results.

Coanda effect on bubble characteristics in a bubbling jet rising near the side wall of a cylindrical vessel

M.IGUCHI et al.

Experimental investigation was carried out on the behavior of an air-water bubbling jet generated vertically upward by air injection through a single-hole nozzle placed near the side wall of a cylindrical vessel. The bubbling jet was pulled towards the side wall, attached to it at a certain vertical distance from the nozzle top, and afterwards rose along it. Such a phenomenon was caused through the Coanda effect. The vertical distance from the nozzle top to the attachment position was defined as the attachment length. This length was closely associated with the gas flow rate and the horizontal distance between the nozzle top and the side wall. The inner diameter of nozzle, however, exerted a negligibly small effect on the attachment length. Bubble characteristics represented by bubble frequency, gas holdup, mean bubble rising velocity and mean bubble chord length were measured with a two-needle electroresistivity probe. The horizontal distributions of the bubble frequency and gas holdup were similar in the vertical region above the attachment position.

Ironmaking and Reduction

Ishida–Wen's model for non-spherical particle

H.W.KANG et al.

Thiele's modulus for non-spherical particle is assumed by introducing the concept of non-spherical radius. Based on this modulus, Ishida–Wen's model for non-spherical particle considering the shape effect is presented. An example of the application of this model to the analysis of gaseous reduction of iron oxide pellets of various shapes is illustrated. According to the analysis result, Thiele's modulus for non-spherical particle is proportional to non-spherical radius as assumed while the rate parameters included in this model are independent of the size and shape of the iron oxide particle.

Modelling of the solids flow in a blast furnace

S.J.ZHANG et al.

A model to describe the solids flow under blast furnace conditions with countercurrent gas flow is developed on the basis of fluid mechanics and the principles of solid mechanics. The surface stress resulting from the interaction among flowing particles is considered to be composed of two parts: rate-dependent and rate-independent. The concept of viscosity is extended to solids flow to represent the hydrodynamic particle–particle interaction (rate-dependent part), and the concept of solid plastic modulus and Coulomb frictional stress relation are employed to describe the frictional contact interaction (rate-independent part). Moreover, a method is proposed to determine the transition between moving and non-moving zones, *i.e.* the profile of stagnant zone. The validity of the model is demonstrated by the good agreement between the model predictions and measurements obtained from a cold physical model of a blast furnace under various flow conditions.

Influence of coal moisture control on carbon deposition in the coke oven chamber

A.FURUSAWA et al.

The carbon deposition mechanism in the free space of coke oven chambers has been studied under Coal Moisture Control (CMC) operation by the actual oven measurements. It was found that the amount of carbon deposits in CMC operation increases as much as 45 to 75 mass% compared with those in wet coal operation. The carryover fines are not negligible mass for the carbon deposits, namely, the carbon deposits on the base portion of an ascension pipe in CMC operation contained about 20 mass% of materials derived from carryover fines, and the majority of the deposits at the initial stage of the carbonization were derived from the carryover fines. The influence of volatile matter on the carbon deposits in CMC operation was greater than that in wet coal operation.

High temperature behavior of Si_3N_4-bonded SiC bricks in blast furnace environment

G.X.WANG et al.

An extensive experimental study has been carried out to better understand the high temperature properties and behaviours, such as oxidation, alkali-erosion and thermal shock resistance of the Si_3N_4-bonded SiC refractory. The mechanism of erosion damage of the Si_3N_4-bonded SiC brick lining in the blast furnace environment was investigated by means of scanning electron microscope (SEM), electron probe micro-analysis (EPMA) and X-ray diffraction (XRD) techniques. The results show that the alkali erosion is mainly caused by potassium penetration into the brick lining. The alkali reactions with the oxidation product SiO_2 result in the formations of low melting point potassium silicates, such as $K_2O \cdot SiO_2$ and $K_2O \cdot 2SiO_2$. These silicates are then peeled off, from time to time, leading to continuous consumption of the SiO_2 layer formed by the oxidation of SiC. Abnormal temperature variations in the furnace wall due to blowing-on or unstable operation will create thermal shock damage to the brick lining and speed up the oxidation and alkali erosion process. As a result of the combined effect of the oxidation, alkali erosion and thermal shock, caves and cracks are generated at the working surface of the SiC brick lining. It is believed that these are the major factors that deteriorate the integrity and stability of the working surface of the SiC brick lining. Based on the current work, an erosion mechanism, namely, oxidation→alkali erosion→melting or peeling-off of silicates→new oxidation and so on, was proposed for the Si_3N_4-bonded SiC brick lining used in the blast furnace.

Weathering study of an industrial coal blend used in cokemaking

R.ALVAREZ et al.

Weathering studies were carried out on a coking coal blend prepared and ground at industrial scale and stored in the open yard. This typical and complex blend, composed of 13 different coals was used by the Spanish Steel Company. Several methods were applied for detecting weathering in the blend. Gieseler maximum fluidity was the most sensitive indicator of the loss of thermoplastic properties. Carbonization tests were carried out in a movable-wall oven and a semi-industrial oven of 6 t capacity. In addition to the measurements of internal gas pressure and coking pressure, laboratory tests were performed to measure expansion/contraction behaviour of the coal blend. A clear decrease in internal gas pressure with weathering was observed in the semi-industrial oven. As regards coke quality, no significant changes were produced in a storage period of ten months, however after this date impairment was observed.

Steelmaking and Refining

Behavior of slag foaming with reduction of iron oxide in molten slags by graphite

L.HONG et al.

Behavior of slag foaming was investigated under the condition of iron oxide reduction by graphite in $CaO–Li_2O–SiO_2–Al_2O_3$ slag systems. Experiments were carried out at 1 573 K, under Ar gas atmosphere with a flow rate of 1 000 N cm^3/min. The SiO_2 molar fraction of the primary slag was varied between 0.33 and 0.49. The initial concentration of iron oxide in the molten slag was varied between 3 and 15 mass%. The content of sulfur ranged from 0 to 0.68 mass%. The rotation speed of graphite rod was kept constant at 1.67 s^{-1}. The slag foaming is evaluated by the ratio of the volume of the gas contained in slag to the total volume of foaming slag, namely gas holdup, ε.

The slag foaming is mainly affected by the CO gas evolution rate. The slag is not foamed when the CO gas evolution rate is less than a critical value. Then with the increase in CO gas evolution rate, the slag foaming becomes vigorous and approaches to a plateau value. Addition of sulfur suppresses the slag foaming and silica favors slag foaming a little.

A simple fluid mechanics model, called drift-flux analysis, can be used to fit the present experimental results.

Casting and Solidification

Prevention of air suction from the contact-part between sliding gate and immersion nozzle

S.YOKOYA et al.

With increasing requirement of steel quality in continuous casting, it is extremely important to regulate reasonably flow rate of molten steel without either biased flow or reoxidation by the suction of air from around the contact-part between sliding gate (SG) and immersion nozzle (SEN). In this study, a novel/minethod to prevent the suction of air from all around the contact-part between the SG and SEN during controlling the flow rate of molten steel, has been developed by giving a step to the SEN. The effects of the step in the SEN on the prevention of air suction from all around the contact-part can be summarized as follows:

(1) The flow squeezed passing through the SG is turned abruptly just before the step in the SEN and, as a reverse flow, passes towards the contact-part between the SG and SEN, where its kinetic energy is converted into the pressure energy as a kind of impinging-flow-action, resulting in a positive pressure on the contact-part.

(2) With increasing amount of sliding-gate-opening, the distance downstream from the gate to the step, that is necessary for the contact-pressure to be positive on the contact-part, becomes wider. Over some opening amount, the contact pressure is always positive on the condition that a dimensionless step width (ratio of step-width to inner-diameter of nozzle) is over 0.15.

From the above-mentioned issues, it is found possible to prevent the air suction from all around the contact-part between the SG and SEN using the SEN with the step beneath the sliding gate.

Roll-strip interfacial heat fluxes in twin-roll casting of low-carbon steels and their effects on strip microstructure

R.P.TAVARES et al.

In twin-roll casting, interfacial heat transfer between the rolls and the solidifying metal can affect strip quality and limit productivity.

In the present work, interfacial heat fluxes between the roll and the solidifying metal were evaluated in a pilot twin-roll caster used in the production of strips of low-carbon steel. This evaluation was based on an inverse heat transfer analysis and on readings of thermocouples inserted at different positions of the roll sleeve of the IMI pilot scale TRC caster in Boucherville, Quebec.

Variations in transient roll-melt interfacial heat fluxes during contact of the freezing shells with the roll surfaces exhibited two patterns, one characterized by a simple peak, the other by a double peak in the heat flux *versus* time curves, depending on the casting conditions. Mechanisms explaining the two types of curve are advanced. Solidification and as-cast structures of strips produced in the pilot caster were also studied, and their characteristics analyzed in terms of fluid flow and heat transfer within the caster's sump.

Analysis and Characterization

The effect of heating conditions on the removal of oxide film on steel surface by the inert gas fusion method

T.ISE et al.

This study was carried out to establish an analytical technique for accurate evaluation of bulk oxygen in ultra-clean steel using the inert gas fusion method without pre-cleaning such as electrolytic or chemical polishing. This method had a two-step heating pattern, one was a continuous heating stage to remove contamination, and another was a fixed high-temperature stage to analysis oxide inclusions. In this paper, reduction sites of oxide film and the effect of bulk carbon content are also discussed. The results obtained are as follows:

(1) The separation of bulk oxygen and contaminant oxygen on the steel surface depended on the heating rate of the steel at heating stage I. The lower the rate was, the better the separation was.

(2) The optimum heating rate of the steel was 1 K/s.

(3) In the case of high-carbon chromium bearing steel which contained 3.4 ppm of oxygen (a calibration standard sample JSS GS-6a), approximately a half of its total oxygen content was estimated to consist of contaminant oxygen on the steel surface. This value was well compared to the measurement by the charged particle activation analysis method and was found to be reasonable.

(4) It was found that both the carbon content in the steel and the feed of carbon from the crucible/steel contact surface affected the removal of oxide film.

Precise morphology analysis on platelet-type hematite particles by transmission electron microscopy

D.NISHINO et al.

The morphological characterization on platelet-type hematite particles was carried out extensively by transmission electron microscopy (TEM). It was found that the thickness of platelet-type hematite particles could be precisely measured from TEM images and convergent-beam electron diffraction (CBED) patterns with the use of the imaging plate. Based on these analyses coupled with electron energy-loss spectroscopy (EELS) which is useful to evaluate the specimen thickness with a simple manner, the mean-free path for inelastic electron scattering of hematite was determined to be 120 nm at an accelerating voltage of 200 kV. Thus, it is expected that the thickness of other hematite particles with various shapes, which is difficult to measure from TEM images and CBED patterns, can now be easily evaluated through EELS.

HREM observation of the interface between Laves-phases and matrix phases in Inconel 718 by using a high-voltage electron microscope

M.SEGAWA et al.

The Ni-base alloy, Inconel 718 was observed with high-resolution electron microscopy using by a high-voltage electron microscope in order to analyze the morphology of the interface between Laves-phases and the austenite matrix phases. The Laves-phase had a plate shape and had a $(004)_{Laves}\|\{111\}_\gamma$; $[1\bar{1}0]_{Laves}\|\langle 110\rangle_\gamma$ relationship in the interface with the matrix (γ). The interface had the step-structure although the interface looked like a planar shape macroscopically. It was considered that the step-structures were introduced to relax the lattice strain between the Laves-phases and the matrix. The step-structures were observed at intervals of almost 11.4–40.4 nm and 2.3–9.6 nm in the samples aged at 1 073 and 1 123 K, respectively. It was considered that the decrease of the interval of step-structure was due to the increase of the lattice strain between the Laves-phases and the matrix with increasing the aging temperature from 1 073 to 1 123 K.

Physical and Mechanical Properties

Fracture properties of multipass submerged arc weld of HSLA steel produced by using flux cored filler wire

P.K.GHOSH et al.

Multi pass submerged arc welding of 25 mm thick structural steel plates has been carried out at different energy input using flux cored filler wire and basic agglomerated flux resulting the weld deposit having chemical composition confirming that of a high strength low alloy (HSLA) steel. Microstructure and hardness of different microstructural regions of the multipass weld has been studied. Tensile properties of the weld deposit has been found out by carrying out tensile test of the weld joint being fractured from the weld. Fracture toughness (K_Q) and fatigue crack growth properties of the weld

are studied and correlated with the welding energy input, microstructure and ultimate tensile strength of the weld. The increase in energy input has been found to reduce the hardness, ultimate tensile strength and yield strength, but to enhance the ductility and K_Q of the weld primarily due to its influence on microstructure of the weld deposit. However, the increase in energy input has been found to reduce the da/dn at higher ΔK but, it has been found to enhance the same at lower ΔK. The K_Q and da/dn of the weld are found to be well correlated with its tensile strength, where an increase in tensile strength reduces the K_Q but enhances the da/dn at ΔK higher than 30 MPa $\sqrt{m}$.

お詫び

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