Fandamentals of High Temperature Processes

Silicon and manganese transfer in dynamic conditions of carbon-saturated liquid iron drops falling through slag layer

A.Wu et al.

Transfer of silicon and manganese as an iron drop falls through a slag layer has been investigated by an experimental study. Carbon-saturated liquid iron drops containing different amounts of silicon were allowed to fall for 1 sec through $CaO-SiO_2-Al_2O_3-MnO$ slag at 1 773 K. The rate of mass transfer of silicon to the iron drop from the slag was found to be two to three orders of magnitude faster than that previously reported in static equilibration laboratory studies. The rate of manganese transfer was dependent on the silicon transfer: when the silicon transfer is fast, the manganese transfer is also fast and *vice versa*. The iron drops broke up while falling through the slag. The results of the present study indicate that for reactions involving solute transfer across liquid-liquid interfaces, significant changes in reaction rate and mechanism occur in dynamic contact conditions. Several possible reasons for these changes are discussed. It was tentatively concluded that the emulsification of the interface plays the major role in enhancing the transfer rates.

The influence of oxygen on the rate of nitrogen absorption into molten iron and Marangoni convection

Zhu J. et al.

Under the condition of non-induction stirring, the Marangoni convection that occurred in the process of nitrogen absorption into the liquid iron with various oxygen contents was investigated. Using the periscopic high temperature lens and X-ray radiography system, the surface velocity induced by the Marangoni effect due to the nitrogen absorption into liquid iron was observed and the surface velocity was measured. The surface velocity decreased with the increase of oxygen contents. In the present study, the rate of nitrogen absorption into liquid iron containing 20~500 ppm oxygen could be described with a first order rate equation, and the process of nitrogen absorption is dominated by the mass transfer in the liquid iron. The apparent mass transfer coefficient was reduced with increasing oxygen concentration. This is mainly due to the dwindling of the Marangoni convection on the surface of liquid iron.

Interfacial properties of dilute Fe-O-S melts on alumina substrates

D.R.Poirier et al.

Compilations and data pertaining to the wettability and interfacial properties of Fe-melts and dilute Fe-O-S alloys on alumina substrates have been collected and compared. The properties included the surface tension of liquid Fe; the surface tension of Al_2O_3; measurements of work of adhesion and contact angles; and the effects of sulfur and oxygen on the surface tension of liquid Fe and on the contact angle. Based on the comparisons, recommendations for estimating these interfacial properties as well as the tension of the Fe-O-S (liquid)/Al_2O_3 interface are given.

Ironmaking and Reduction

Prediction of blast furnace performance with top gas recycling

P.R.Austin et al.

Top gas recycling has been suggested as a method for reducing blast furnace fuel rates and thus reducing carbon emissions from the ironmaking process. Three methods of top gas recycling are numerically investigated using a mathematical model to predict the furnace performance at fixed blast volume and constant coke, ore and pulverised coal compositions with varying recycle volumes. For each recycling method, a first calculation sequence is performed varying recycle volume at fixed ore: fuel ratio, and also a second sequence at fixed average liquid metal outflow temperature.

Simple replacement of normal blast gases with recycled top gas is predicted to cause the production rate to decrease and the fuel rate to increase. Likewise, oxygen enriched blast replacement has similar effects, although the severity is less as the blast oxygen rate is maintained in this case. Both of these methods reduce furnace efficiency. Hot reducing gas (HRG) replacement, where CO_2 is stripped from the recycled gas, leads to an increase in production of up to 25 % with a simultaneous decrease in fuel rate of 20 % at fixed metal temperature. These calculations show that top gas recycling could be used to increasing furnace efficiency while decreasing carbon emissions thus making a positive contribution to efforts to prevent global warming.

Analysis of actual blast furnace operations and evaluation of static liquid holdup effects by the four fluid model

P.R.Austin et al.

The purpose of this paper is to extend and validate a previously presented model of the blast furnace shaft. This model uses conservative differential equations to analyse simultaneous four phase motion, heat transfer and chemistry. First, the paper describes some enhancements to the model. After this, the model is validated against several sets of operational and descending probe data from various blast furnaces. The calculated temperature fields show good agreement with two dimensional fields measured by descending probes at both medium and high rates of PC injection. Finally, the third section considers the effect of including static liquid holdup on the model predictions. Three correlations for static liquid holdup were examined. For all correlations, when static liquid holdup was included in the calculations the net liquid flux towards the raceway increased due to the transport of static liquid by the solid. Further, as static holdup reduces the volume available for gas flow, the gas velocity increases causing greater gas-solid heat transfer. This increases the rates of direct reduction and solution loss, resulting in increased predicted production rates and decreased hot metal and top gas temperatures. Finally, for correlations that predict large static holdup in the raceway region, silicon transfer to hot metal is increased due to increased liquid metal residence times.

Steelmaking and Refining

Reoxidation behavior of molten steel in non-killed and Al-killed steels

H.Goto et al.

The effect of soluble oxygen on the reoxidation behavior by slag has been investigated by comparing the oxygen content and oxide formation of non-killed steel containing a soluble oxygen content of approximately 50 to 250 mass ppm with those of Al-killed steel containing less soluble oxygen. In the non-killed steel, oxides are not formed in molten steel even when oxygen is supplied from slag because it does not contain aluminum which has strong affinity for oxygen. The soluble oxygen content simply increases. In the Al-killed steel, however, the oxygen supplied from slag reacts with aluminum to form alumina and most of them float out.

A new approach to model sulphur refining in a gas-stirred ladle—a coupled CFD and thermodynamic model

L.Jonsson et al.

In the present work, a new modelling approach has been put forward to study slag-metal reactions. Sulphur refining in a gas-stirred ladle has been taken as an example. A two-dimensional fluid dynamic model accounting for the steel, slag and argon phases has been incorporated with the thermodynamics of desulphurisation. Comparison of the results of the model calculation with plant data from Ovako Steel indicates that the present approach has great potential. It has opened up the possibility of developing process models based on fundamental equations.

Casting and Solidification

Radiative heat transfer through mold flux film during initial solidification in continuous casting of steel

J.Cho et al.

Absorption coefficient and extinction coeffi-

cient for various commercial mold fluxes have been determined to quantify the radiative and the overall heat transfer through the flux film in continuous casting mold. The absorption coefficient is found to be less than 1 000 m^{-1} for glassy specimens whereas the extinction coefficient is *ca.* 3 000~30 000 m^{-1} for crystalline ones. Comparison of observed with calculated radiative heat flux from the absorption coefficient has shown that gray gas approximation is valid for evaluating the radiative heat flux across the mold flux film. Numerical calculation for both radiative and conductive heat transfer has been carried out for a given total thickness of the flux film. Despite little difference in optical properties among various mold fluxes, the radiative heat flux through molten layer of the flux films for low carbon and ultra low carbon steel is found larger than that for medium carbon steel. This is due to increasing thickness ratio of molten layer to crystalline layer of flux films. Solidifying and crystallizing behavior of mold fluxes is a key factor to control the radiative heat transfer in continuous casting mold, accordingly.

Forming Processing and Construction

Geometrical characteristics of pulsed current positional GMA weld

H.S.RANDHAWA et al.

Vertical up positional welding of structural steel plate was performed by pulsed current GMAW process employing comparatively high mean currents of 100 and 130 A, resulting an enhanced deposition rate. The use of welding current of conventional continuous current GMAW at similar order to those of the mean currents of the pulsed current GMAW process is found unsuitable in present conditions of welding. However, the geometrical characteristics of the weld are found to be largely governed by the pulse parameter of the GMAW process and they are well correlated to a factor ϕ defined as a summarized influence of pulse parameters such as peak current, base current, pulse off time and pulse frequency. The increase in ϕ at a lower mean current is found favourable to obtain acceptable weld geometry, especially with respect to the form factor and toe angle of the top reinforcement of the weld.

Surface Science and Technology

Structure of protective rust layers formed on weathering steels by long-term exposure in the industrial atmospheres of Japan and North America

M. YAMASHITA et al.

A protective and adherent rust layer develops on weathering steels during outdoor exposure. This layer acts as a barrier which slows further corrosion, thus enabling weathering steel to be used in structural applications without painting. To aid in understanding the mechanism of protective rust formation, studies have been made on the composition and microstructure of these layers. The present study was jointly conducted on Japanese weathering steel exposed in the industrial environment of Amagasaki, and US weathering steel exposed in the industrial environment of Bethlehem. The rust layers were studied by use of optical microscopy, electron microscopy with X-ray fluorescence, X-ray diffraction, and micro-Raman spectroscopy. The results of this collaboration show that, in general, the rust layers formed during long-term exposure are composed of one or more alternating layers of goethite and lepidocrocite, with scattered patches of maghemite and/or magnetite.

Physical and Mechanical Properties

Improvement of creep rupture ductility in Ni base superalloy Nimonic 80A and its material properties

A.FUJITA et al.

Superalloys of Refractaloy 26 (R-26) and Nimonic 80A are used as high temperature bolt materials for steam turbines. R-26 has both high creep rupture strength and high creep rupture ductility, and is therefore highly reliable as a high temperature bolt material. However, because it is an austenitic steel having a large thermal expansion coefficient, whereas the material for the turbine casing in ultra high temperature turbine plants is a high Cr cast steel of the martensite system, the resulting differential thermal expansion leads to insufficient fastening force for the turbine casing. Nimonic 80A, an austenitic steel like R-26, does not show such a large thermal expansion coefficient, and the problem as seen in R-26 can thus be eliminated in terms of bolt fastening force for the turbine casing. However, because the creep rupture ductility of Nimonic 80A is low, its reliability in terms of high temperature strength can be insufficient.

In the present study, therefore, improvement of creep rupture ductility in Ni base superalloy Nimonic 80A was undertaken through improvement of chemical composition and heat treatment method. The investigation results confirmed that creep rupture ductility can be improved by reducing the Ti content and providing 3-step aging treatment. Furthermore, based on these findings, an actual size bolt material sample was produced to evaluate its material properties, and this material demonstrated good material properties as seen in basic test results.

The formation of deformation induced ferrite during mechanical testing

J.R.LEWIS et al.

The effects of austenite grain size, level of undercooling, and strain and strain rate in compression on the austenite-to-ferrite transformation were investigated in a 0.1 % C, 1.4 % Mn steel. The influence of this transformation on the hot ductility was then examined. Straining was found to raise the effective Ar_3 temperature almost to the Ae_3, and to accelerate the transformation significantly in both fine (~25 μm) and coarse (~200 μm) grained samples. At relatively low levels of undercooling (~40 °C), deformation induced ferrite only formed in regions that were significantly affected by the applied strain. In tension, it was observed that, if thin bands of grain boundary ferrite were present in the microstructure, the ductility decreased significantly and failure always occurred in this second phase. Increasing the strain rate significantly reduced the depth of the ductility trough across its entire width. It is concluded that, for the steel in question, unbending after continuous casting should be performed at strain rates in excess of 3×10^{-2} s^{-1} to ensure good ductility.

New Materials and New Processes

In-situ joining of nickel monoaluminide to iron by reactive sintering

K.MATSUURA et al.

A cylindrical block of nickel monoaluminide, NiAl, is produced from a mixture of nickel and aluminum powders by sintering a powder compact under a pseudo isostatic pressure, and is simultaneously joined to an iron block with the same shape. When the joining couple of the powder compact and the iron block is heated to approximately 900 K, a violent exothermic synthesis reaction, Ni+Al→NiAl, suddenly starts, and the temperature of the compact quickly rises owing to the heat of reaction and exceeds the melting point of NiAl, 1 911 K. Because the molten NiAl wets the contacting surface of the iron block, an iron-rich NiAl-base alloy and an iron-base ternary solid solution are produced on each side of the joining interface. No cracks or cavities are formed in the NiAl even in the vicinity of the joining interface. Hardness continuously changes across the joining interface from approximately 330 in NiAl to approximately 55 in iron. All of five specimens of a four-point bending test fractured in NiAl, the fracture surface being 1 to 2 mm away from the joining interface.