（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Fundamentals of High Temperature Processes

Surface tension of liquid Fe–Ti alloys at 1 823 K

J.LEE et al.

Surface tension of liquid Fe–Ti alloys has been determined by using the constrained drop method at 1 823 K in Ar–10%H_2 gas atmosphere. It was found that the surface tension of liquid Fe–Ti alloy decreases slightly with increasing titanium content. In addition, the surface tension of Fe–Ti alloy was also obtained by a theoretical calculation. It was found that the experimental results became slightly lower than the calculated results with increasing titanium content. This paper also discusses the possible reasons for the slight decrease in the surface tension with increasing the titanium content.

(cf. *ISIJ Int.*, **46** (2006), 467)

Effect of sulfur and oxygen on engulfment and pushing of deoxidation particles of ZrO_2 and Al_2O_3 during solidification of Fe–10mass%Ni alloy

H.OHTA et al.

The effect of sulfur and oxygen on engulfment and pushing of deoxidation particles of Al_2O_3 and ZrO_2 during solidification of an Fe–10mass%Ni alloy has been studied. The Al_2O_3 and ZrO_2 particles are pushed to the interglobular region where the particle coagulation takes place with an increase in sulfur content. The sulfur contents at the engulfment and pushing transition for ZrO_2 and Al_2O_3 particles are 300 to 400 and about 100 mass ppm, respectively. The ZrO_2 and Al_2O_3 particles are pushed to the interglobular region with an increase in oxygen content. The effect of sulfur and oxygen on engulfment and pushing of particles has been discussed based on the interfacial energy/wetting model and the critical velocity for the engulfment and pushing transition.

(cf. *ISIJ Int.*, **46** (2006), 472)

Precipitation and dispersion control of MnS by deoxidation products of ZrO_2, Al_2O_3, MgO and MnO–SiO_2 particles in Fe–10 mass%Ni alloy

H.OHTA et al.

An Fe–10 mass%Ni–1mass%Mn alloy was deoxidized with Zr, Al, Mg and Si and the effect of these deoxidation particles on MnS crystallization and/or precipitation has been studied as a function of S content with forcussing on the particle dispersion in microsegregation domain. MnS cannot be uniformly dispersed in microsegregtion domain since the crystallization and/or precipitation of MnS occur only on ZrO_2 or Al_2O_3 particles located at the region of final solidification. MnS-containing MnO–SiO_2 particles can be uniformly dispersed in microsegregation domain, if the S level is low enough for particles not to be pushed. MgS and/or (Mg, Mn)S crystallize on MgO particles in Mg deoxidation. In the case of high S level, the MgO, MgS/MgO and (Mg, Mn)S/MgO particles are pushed to the region of final solidification and then MnS crystallizes and/or precipitates on the pushed particles.

(cf. *ISIJ Int.*, **46** (2006), 480)

Reaction mechanism between solid CaO and FeO_x–CaO–SiO_2–P_2O_5 slag at 1 573 K

T.HAMANO et al.

Solid CaO and FeO_x–CaO–SiO_2–P_2O_5 slag were reacted for 2 to 2 400 s at 1 573 K. The interface of CaO and slag were observed and analyzed by SEM/EDS. The CaO–FeO layer was formed beside solid CaO. The thickness of the CaO–FeO layer increased with time. Next to the CaO–FeO layer, $2CaO \cdot SiO_2$ phase was formed in the melt and high content of FeO was included in the liquid. The activities of FeO and CaO for each phase were evaluated and reaction mechanism between solid CaO and FeO_x–CaO–SiO_2–P_2O_5 slag was discussed. The activity of FeO for $2CaO \cdot SiO_2$ saturated melt is larger than that for the CaO–FeO layer, therefore, Fe^{2+} diffuses from slag phase to solid CaO. Then the CaO–FeO layer is formed beside solid CaO. The pass of the slag composition change accompanied by CaO dissolution are represented in the phase diagram for the FeO_x–CaO–(SiO_2+P_2O_5) pseudo ternary system.

(cf. *ISIJ Int.*, **46** (2006), 490)

Ironmaking

Governing processes of gas and oil injection into the blast furnace

D.ANDAHAZY et al.

To enhance the blast furnace process, the practice of injecting reducing agents into the blast furnace is used. In a metallurgical plant of the voestalpine Stahl, so far the injection of oil is practiced. The availability of gases like coke oven gas (COG) makes it possible to substitute reducing agents like heavy oil. The injection of gas and oil, respectively, shows different reaction characteristics and therefore different reducing conditions are obtained.

In this work, theoretical considerations are made about the different conversion characteristics of oil and gas. The calculations, done by using computational fluid dynamics (CFD), provide a detailed description of the oil and gas flow injected in the hot blast. For gas injection, the mixing of gas and blast and their conversion are considered in tuyere and raceway. For oil injection, additionally the evaporation of the oil droplets takes place.

The injection of gas with one lance shows an inhomogeneous distribution in temperature and velocity due to the high injection velocity compared to oil injection. For the injection of oil, evaporation of the oil droplets takes place and the gas formed reacts with the hot blast. There, the distribution of temperature, velocity and concentrations is more homogeneous than for gas injection. A variation of the oil droplet size injected shows for larger droplets (400 μm and more) an incomplete evaporation and distributions similar as for the gas injection.

(cf. *ISIJ Int.*, **46** (2006), 496)

Influence of mineral matter on coke reactivity with carbon dioxide

M.GRIGORE et al.

A method to improve blast furnace efficiency and make it sustainable is to lower the temperature of the iron oxide reduction using a highly reactive coke. Understanding the role of coal rank, maceral composition and mineral matter in coke in the gasification reaction under these new conditions is of major importance. Four cokes prepared from Australian coals of varying rank, maceral composition and ash composition were gasified with carbon dioxide. The rank and maceral composition of the parent coals did not appear to be related to the reactivity of the cokes. However, coke reactivity increased with increasing total amount of catalytic minerals in crystalline phases such as metallic iron, iron sulfides. Calcium sulfide could be a potential catalyst for the gasification reaction. Iron, potassium and sodium present in the amorphous phase did not appear to have any effect on coke reactivity. Calcium was present only in the crystalline phases. Knowing the form and amount of the mineral phases that catalyse the gasification reaction in coke would improve the ability to predict coke reactivity. This knowledge would contribute to more efficiently matching cokes to blast furnace requirements.

(cf. *ISIJ Int.*, **46** (2006), 503)

Development of high ratio coke mixed charging technique to the blast furnace

S.WATAKABE et al.

Technique for high ratio coke mixed charging was developed and applied at JFE Steel's East Japan Works (Chiba District) No. 6 blast furnace as the first case of application to a large blast furnace. Simultaneous discharging of ore and coke from the top bunkers, and the precise control of burden distribution technique with the mathematical model considering the segregation behabior of mixed layer have made it possible. Since April 2002, high productivity operation with the world's lowest level of sinter ratio has been conducted using high ratio coke mixed charging technique.

(cf. *ISIJ Int.*, **46** (2006), 513)

Steelmaking

Physical-modeling study of fluid flow and gas penetration in a side-blown AOD converter

M.BJURSTRÖM et al.

The main fluid-flow pattern that results in a converter with side gas injection was studied using physical modeling. Having roughly the same viscosity as liquid steel, water was used in the experiments. The velocity of the water was determined for different positions in the vessel symmetry plane by laser Doppler velocimetry. Experiments were performed using combinations of three different bath heights and four different gas-flow rates. The results showed penetration of the gas plume into the steel bath both at the tuyère and bath level to increase with an increased gas-flow rate. Also, the penetration depth of the gas both at the tuyère and bath surface level were more affected by an increased gas-flow rate than an increased bath height. Finally, the overall fluid-flow pattern in the system was found to change both with an increased bath height and an increased gas-flow rate.

(cf. *ISIJ Int.*, **46** (2006), 523)

Reduction behaviors of hot metal dephosphorization slag in a slag regenerator

M.ISHIKAWA

The reduction behavior of dephosphorization slag on the iron bath in the reduction furnace of the slag regeneration process was researched by test converter experiments. Dephosphorization slag and coke as the reduction agent and the heat source were added to the hot metal in the converter and oxygen was blown through the top lance. During the blowing, the reduction of (P_2O_5), (FeO) and (MnO) in the slag proceeded simultaneously. The amount of phosphorus and manganese oxide in the slag decreased and the amount of phosphorus and manganese in the metal increased in turn during the reduction. The unknown amount of these elements which occupied about 20% of total input also existed. The unknown parts of phosphorus and manganese in material balance are seemed to be caused mainly by the vaporization of phosphorus and manganese from the droplets generated by the reduction at the slag/coke interface.

(cf. *ISIJ Int.*, **46** (2006), 530)

Casting and Solidification

3-D inverse problem continuous model for thermal behavior of mould process based on the temperature measurements in plant trial

Y.HEBI et al.

A three-dimensional mathematical model for round billet continuous casting of steel in the mould, adopting the surface revolution theory, together with an appropriate inverse problem method from the measured temperatures by the thermocouples buried in various locations in the mould, has been developed to elucidate the real thermal behavior of mould process in plant production, including the mould heat transfer, steel solidification, and slag film distribution, with the objective of understanding the relationship among them. The results show that the vertical component of heat condition and the slag rim at meniscus decreases mould temperatures and the former also lower the level of the peak temperature, and the minimum thickness of solid slag film about 80 mm below meniscus results in the peak mould heat flux and temperature. The magnitude and profile of mould heat transfer around the perimeter between the shell and mould, having corresponding relationship with solid slag, determines that of shell thickness. And the channel the liquid slag entering at meniscus determines the mould heat transfer to some extent.

(cf. *ISIJ Int.*, **46** (2006), 539)

3D stress model with friction in and of mould for round billet continuous casting

Y.HEBI et al.

A three-dimensional, thermo-elasto-plastic finite element stress model with temperature-dependent thermal-physical mechanical properties, to compute the thermo-mechanical state of the solidifying shell and the distortion of mould during continuous casting of steel for a round billet has been developed to investigate the influence of mould friction on the strand stress. A method is applied to prevent penetration of the shell into the mold wall due to the ferrostatic pressure and excessive mould taper. Slag film thickness, air gap size and the contact state between the shell and mould have been predicted based on shell shrinkage and mould distortion including the mould taper, associated with their temperature fields. Ultimately, the influence of mould friction on the strand stress was also investigated. And the calculation results show that the magnitudes of the influence of mould friction on strand stress vary with various contact states, such as liquid slag film, direct contact, and air gap, between the shell and mould from one location to another.

(cf. *ISIJ Int.*, **46** (2006), 546)

Forming Processing and Thermomechanical Treatment

Finite element analysis of tilting of metal in bar rolled with three-roll mill

M.ASAKAWA et al.

Rolled metal bars and rods often exhibit tilting, which is rotation of the material around the pass line under rolling. Tilting may result in a defective shape. High dimensional accuracy is demanded in 3-roll rolling because 3-roll rolling is used for finishing passes. Therefore, the design of calibers and a rolling sequence that can reduce tilting is important from industrial aspects. In this study, three-dimensional FE analysis is applied to the prediction of metal tilting under 3-roll rolling in an oval-round pass and a hexagon-oval pass. The difference in the characteristics of tilting according to the contact contour between metal and the roll is investigated by classifying the characteristics of tilting into two modes, with the aim of clarifying the threshold for the occurrence of overturning and restoration resulting from tilting. Predicted results agree well with the experimental measurements of tilting, and the validity of method for analyzing tilting is confirmed. Moreover, it is found that the mechanism of tilting differs according to the contact contour. In an oval-round pass that is of a convex contact type, the bar tilt angle is difficult to decrease once tilting has occurred. In a hexagon-oval pass that is of a concave contact type, although the bar tilt angle tends to increase when the entrance cross section is constrained strongly, the bar tilt angle tends to decrease after constraint becomes relatively small.

(cf. *ISIJ Int.*, **46** (2006), 553)

A probabilistic approach to model interfacial phenomena during hot flat rolling of steels

S.DAS et al.

The conventional method of representing the nature and magnitude of heat transfer at the strip–roll interface during hot rolling is to use a mean or "average" heat transfer coefficient (h). However, an examination of the real strip surface reveals a spatial variation of features, characterised by varying asperities and distributed topography of the oxide scale. The scale distribution can vary both along and across the strip, with details being dependent on the rolling schedule, thereby rendering formulations that use a mean h-value good only to a first approximation.

The paper develops a probabilistic approach, implemented within a conceptually flat and thin imaginary oxide layer, the so-called "phantom layer", to gain an insight into the probable natural variation of the heat transfer coefficient at the strip–roll interface. Here, the evolving oxide-scale parameters of instantaneous reduction, thickness and temperature are process-driven random variables whose cumulative effect on the instantaneous h is derived using a Probability Distribution Diagram (PDD).

The PDD model proves to be particularly useful in addressing the practical issues of non-uniformity and local scale variations.

(cf. *ISIJ Int.*, **46** (2006), 560)

Surface Treatment and Corrosion

Influence of phosphorus, sulpher, and oxygen on 65% nitric acid corrosion resistance of super high-clean 316L stainless steel

K.SAKURAYA et al.

For the purpose to verify the effect of decreasing phosphorus on corrosion properties of stainless steels, corrosion resistant tests in 65% nitric acid solutions were carried out for super-low phosphorus content 316L type stainless steels which were manufactured by the cold crucible type levitation melting method using Ca–CaF_2 flux for aiming at the dephosphorization. By decreasing phosphorus content in these steels from 0.026 to 0.0002 mass%, the corrosion rate in 65% nitric acid solutions decreased remarkably. Especially even under 0.001% phosphorus content, the improvement of corrosion resistance against nitric acid solution could be observed.

As for the non-metallic tramp elements, there were linear relations between corrosion rate and the very small amount of sulfur and oxygen contents in the super-low phosphorus stainless steels containing under 0.0002 mass% phosphorus. So the super high purification of these elements is also very effective for the improvement of corrosion resistance against nitric acid solutions.

It is known that the corrosion of austenitic stainless steels containing over 0.003 mass% phosphorus in nitric acid solutions is intergranular corrosion. In the present work, it was confirmed that the corrosion of super-low phosphorus content 316L type stainless steels even at 0.0002 mass% was not uniform corrosion but intergranular corrosion.

(cf. *ISIJ Int.*, **46** (2006), 567)

A noble gas wiping system to prevent the edge overcoating in continuous hot-dip galvanizing

K.J.AHN et al.

A noble method is proposed to prevent the edge overcoating (EOC) that may develop near the edge of the steel strip in the gas wiping process of continuous hot-dip galvanizing. In our past study (*ISIJ International*, Vol. 27 (2003), No. 10, pp. 1495–1501), it was found that the EOC is caused by the alternating vortices which are generated by the collision of two opposing jets in the region outside the steel strip. In the present study, the flow field around the

gas wiping system has been analyzed numerically and it was found that when the two opposing jets collide at an angle much less than 180°, the alternating vortices disappear and the impinging pressure on the steel strip surface becomes nearly uniform. In order to deflect both jets downward by a certain angle, a cylinder with small diameter is installed tangentially to each exit of the lower lips of the two-dimensional opposing jets. The three dimensional flow field with the proposed device is analyzed numerically by using the commercial CFD software, STAR-CD. And the coating thickness is calculated by solving the boundary layer momentum equation with an integral analysis method. In order to compare the present noble method with the conventional edge baffle plate method to prevent the EOC, the flow field with edge baffle plates is also calculated. The calculation results show that the tangentially installed cylinder at the lower lip of the jet exit is significantly more effective than the edge baffle plate.

(cf. *ISIJ Int.*, **46** (2006), 573)

Transformations and Microstructures

The onset temperatures of γ to α-phase transformation in hot deformed and non-deformed Nb micro-alloyed steels

X.Q.YUAN et al.

In the present paper, continuous cooling transformation behaviors in Nb micro-alloyed steels were systematically investigated by the thermal dilatation method, during which the effects of Nb contents and hot deformation of austenite on phase transformation behaviors, especially the transformation start temperatures, were studied in detail. The tests were carried out with the samples having been reheated+hot deformed or reheated+non-deformed prior to the dilation measurements. It was found that the A_{r3} temperatures measured from the dilatometric curves changed with increasing Nb content in parabolic ways under both hot deformed and non-deformed conditions. It is believed that dissolved Nb in austenite may have had the Nb solute drag effect that could delay austenite to ferrite transformation. On the other hand, Nb precipitates in austenite could retard the growth of austenite grains and act as potential nucleation sites, both of which could enhance the transformation kinetics. Also, the interaction of strain, precipitation and temperature was estimated by using the Sellars model, which predicted that the strain induced precipitation had occurred in hot deformed Nb steels before phase transformation started, and in non-deformed steels with Nb content greater than 0.023 mass%, precipitation was also likely to have occurred under slow cooling rate before phase transformation started, which could have played an important role in determining A_{r3}. These factors worked together to make A_{r3} changing with Nb content in the parabolic way. Based on the experimental results, a mathematical model for the A_{r3} calculation for Nb and C–Mn steels were developed, which exhibited a good accuracy in predicting the A_{r3} of the steels with and without hot deformation.

(cf. *ISIJ Int.*, **46** (2006), 579)

Mechanical Properties

Impact toughness prediction for TMCP steels using knowledge-based neural-fuzzy modelling

M-Y.CHEN et al.

As one of the most important characteristics of structural steels, toughness is assessed by the Charpy V-notch impact test. The absorbed impact energy and the transition temperature defined at a given Charpy impact energy level are regarded as the common criteria for toughness assessment. This paper aims at establishing generic toughness prediction models which link materials compositions and processing conditions with Charpy impact properties. Hybrid knowledge-based neural-fuzzy modelling techniques which incorporate linguistic knowledge into data-driven neural-fuzzy models have been used to develop the Charpy impact properties prediction models for thermo-mechanical control process (TMCP) steels. Two basic ways of knowledge incorporation are discussed and used to improve the performance of the obtained fuzzy models. Simulation experiments show that both numeric data and linguistic information can be combined in a unified framework and that both Charpy impact energy and the impact transition temperature (ITT) can be predicted by the same model.

(cf. *ISIJ Int.*, **46** (2006), 586)

The effect of boron on hot ductility of Nb-microalloyed steels

F.ZARANDI et al.

Two grades of the Nb-containing steel, one modified with B, were examined in order to study the effect of B on the hot ductility. Since the hot ductility loss of the Nb-containing steel during the continuous casting is manifested as surface cracking, the surface thermal schedule including *in situ* melting was taken into account. The results revealed that addition of B improves the hot ductility of austenite. Two mechanisms for such improvement are proposed that are not based on the presence of intragranular ferrite. These mechanisms concern with depletion of strengthening elements in the austenite lattice through faster kinetics of grain boundary precipitation and non-equilibrium segregation of precipitants.

(cf. *ISIJ Int.*, **46** (2006), 591)

Effects of nitrogen on the mechanical properties of old rolled TRIP-aided steel sheets

S.C.BAIK et al.

Tensile tests were conducted in order to study the effects of nitrogen on the mechanical properties of the 0.2C–1.5Mn–1.5Si–0.04Al–(0.003–0.015)N steels often annealing at 800–830°C, followed by the austempering at 400–450°C. The results show that both tensile strength and elongation increase and the balance of tensile strength×elongation are improved upon nitrogen addition to the TRIP steel. It was found that the density of AlN precipitates increases with addition of nitrogen. The volume fraction of retained austenite increases due to AlN precipitation, because the precipitates retard the transformation of austenite during cooling and austempering. As a larger volume fraction of austenite remained after annealing has been transformed to martensite during deformation, elongation as well as strength has increased in the nitrogen added steel. It is also observed that the average grain size of ferrite and bainite decreases because of AlN precipitation that hinders grain growth. The refinement of ferrite and bainite by AlN precipitates also contributes to the increase in the strength of nitrogen added steels.

(cf. *ISIJ Int.*, **46** (2006), 599)

Physical Properties

Density measurements of mould flux slags by electrostatic levitation method

T.MATSUSHITA et al.

In the present work, the densities of a mould flux slag were measured as a function of temperature by electrostatic levitation (ESL) method. The density of a mould flux, as measured by ESL method decreased linearly with increasing temperature. The results obtained are compared with the value measured by the sessile drop method just above the melting point of the slag. The discrepancies are explained on the basis of the inherent merits and demerits of the two types of measurements. The experimental values of present work were also compared with the density data for other mould flux slags from Swedish plant practice, obtained by the sessile drop method as part of the present work as well as literature data. A thermodynamic model of molar volume, developed in the present group was used to predict the density of slags. The molar volume was described as a function of integral molar enthalpies of mixing. In the case of ternary systems corresponding to the mould flux slag, the calculated values are in reasonable agreement with the experimental values.

(cf. *ISIJ Int.*, **46** (2006), 606)