（＊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

Evaluation of surface tension of molten slag in multi-component systems

M.HANAO et al.

A thermodynamic model for determining the surface tension of molten ionic mixtures, derived by considering the ionic radii of the components, was extended to multi-component slag systems. The composition dependence of the surface tension in 6-component systems of the type CaO–SiO_2–Al_2O_3–MgO–Na_2O–CaF_2 was evaluated with the present model using information based on the surface tension and molar volume of the pure oxide components, and on the anionic and cationic radii. The evaluated results for the surface tension agree well with literature data.

(cf. *ISIJ Int.*, **47** (2007), 935)

Numerical simulation on a horizontal flow pattern of jet-induced rotary sloshing in a cylindrical container

Y.UEDA et al.

Self-induced rotary sloshing caused by an upward round jet in a partially filled cylindrical container is numerically simulated to investigate the variation of flow pattern in horizontal cross-sections, which are from inside to outside the rotary sloshing. A molten steel jet could be also observed in a cylindrical reactor and, hence, the jet-induced rotary sloshing is thought to be useful for the development of a refining process. Visualization technique employed in this study includes Computational Fluid Dynamics (CFD). Results for the horizontal flow pattern and the velocity profile are computed and tested against the previous PIV result. In addition, a circular trajectory of the peak point of a free surface swell caused by the inlet jet is computationally given.

(cf. *ISIJ Int.*, **47** (2007), 940)

Thermodynamics of aluminum, nitrogen and AlN formation in liquid iron

W.-Y.KIM et al.

Thermodynamics of aluminum, nitrogen and AlN formation in liquid iron was investigated using the metal–nitride-gas equilibration under various nitrogen partial pressures in the temperature range of 1 873–1 973 K. The nitrogen solubility in liquid iron decreased with aluminum additions. Pure solid AlN was formed at critical contents of aluminum and nitrogen in liquid iron. The experimental results were thermodynamically analyzed using Wagner's interaction parameter formalism to determine the first-order interaction parameter of aluminum and nitrogen, the first-order self interaction parameter of aluminum, and the equilibrium constant for the formation of pure solid AlN in liquid iron as follows.

$$e_N^{Al} = -332.2/T + 0.194$$

$$e_{Al}^{Al} = 111.0/T - 0.016$$

$$AlN\,(s) = Al + N$$

$$\log K_{AlN} = -16\,560/T + 7.4$$

Thermodynamics of aluminum in liquid iron could be well described by Darken's quadratic formalism, and the values of $\alpha_{Fe\text{–}Al}$ and γ_{Al}° were determined as follows.

$$\alpha_{Fe\text{–}Al} = -1\,112/T - 0.585$$

$$\gamma_{Al}^{\circ} = -185.0/T + 0.165$$

(cf. *ISIJ Int.*, **47** (2007), 945)

Characterization and reduction of interactive forces among magnetically driven arcs

T.YAMAMOTO et al.

Interactive forces among magnetically driven arcs were considered theoretically. It was assumed that several plasma torches were arranged in parallel under an alternating external magnetic field, which drove the arcs to produce an oscillatory motion of their anode roots. The electromagnetic interaction among arcs causes their mutual attraction, thereby disturbing their oscillatory motions.

A new method to reduce such disturbance was proposed by arranging additional current paths. Their optimum position and currents to be supplied were calculated for cancellation of attractive interactions among arcs.

(cf. *ISIJ Int.*, **47** (2007), 955)

Plasma behavior under imposition of alternating magnetic field perpendicular or parallel to the plasma arc current

Y.YAMAMOTO et al.

Thermal plasma has advantages such as clean energy, good controllability, high power density and so on. Therefore, it has been applied to the steel industry such as heat source of molten steel in a tundish and secondary refining. For these processes, precise control of the plasma is requested for high efficiency and for high-quality products. Because the plasma is electrically conductive fluid, a magnetic field is one of the powerful tools to control its behavior under non-contact operation. Therefore, investigations to control the plasma using the magnetic field have been done. In this investigation, a DC transferred plasma arc behavior has been investigated under imposition of an alternating magnetic field of frequency range between 5 Hz and 2 000 Hz in which the magnetic field direction is perpendicular or parallel to the plasma arc current. The forces governing the plasma behavior is estimated by the simple calculation of forces acting the plasma. Under the imposition of the perpendicular magnetic field to the plasma arc current, a plasma oscillation width is constant when the magnetic field frequency is less than 50 Hz, while it decreases with increase in the magnetic field frequency if the frequency is larger than the 50 Hz. Under the imposition of the parallel magnetic field of 1 000 Hz to the plasma arc current, a burned area on a copper block by the plasma is smaller than that without the magnetic field while the burned area with the low frequency magnetic field less than 1 000 Hz is larger than that without the magnetic field.

(cf. *ISIJ Int.*, **47** (2007), 960)

Ironmaking

Predicting granulating behaviour of iron ores based on size distribution and composition

J.KHOSA et al.

Increased demand and diminishing high grade resources have resulted in a large diversity of iron ore sources used in the modern steel mill. Using research on the effect of ore type and size on granulation for single ore blends containing coke, flux and returns, this paper presents a study to model the optimum granulating moisture and related green bed permeability of an iron ore from the size distribution and composition of the ore when added in a simplified sinter blend.

The models developed from the granulation test work are applied to a broad range of iron ore types and blends. The effect of particle size on granulation is also quantified across a range of iron ore types.

It was found that the optimum moisture could be described accurately by knowing the ore's SiO_2, LOI_T and Al_2O_3 (−1 mm) content, as well as the −0.15 mm and percentage of Intermediate (0.1 to 1 mm) size fractions. It was also found that for most iron ores, an increase in particle size close to the 0.1 mm size range has the greatest effect of reducing permeability and increasing granulating moisture.

(cf. *ISIJ Int.*, **47** (2007), 965)

Observations of the mineral matter material present at the coke/iron interface during coke dissolution into iron

M.W.CHAPMAN et al.

In this study, the mineral matter layer that forms between coke, and liquid iron during carbon dissolution has been characterised. Rectangular prisms of coke were immersed in an iron–2 mass% carbon melt at representative ironmaking temperatures for 20 min then drop quenched. The quench sample was then sectioned and the coke–iron interface was examined in the SEM. A mineral matter layer was observed at the experimental temperatures 1 400°C, 1 450°C and 1 500°C, but not at 1 550°C. Though no layer was found at 1 550°C a slag was observed on the metal surface. This slag was not evident at other temperatures. The formation of the mineral matter layer and its temperature dependence is described in terms of a temperature activated fusion process. Further the mineral matter layer and adjacent coke were found to be significantly depleted in SiO_2. This has been explained in terms of SiO_2 reduction.

(cf. *ISIJ Int.*, **47** (2007), 973)

Casting and Solidification

Water-model experiment on melting powder trapping by vortex in the continuous casting mold

N.KASAI et al.

Water-model experiments have been carried out to understand the behavior of mold powder trapping phenomena by vortex in continuous casting mold. The following findings are obtained.

(1) Mold powder trapping by the vortex occurs irregularly near the immersion nozzle. It occurs only

in the wake of the immersion nozzle.

(2) As for the occurrence frequency ratio of the vortex, the maximum value appears in the water flow rate regime ranging from 61.4 to 70.2 L/min. This regime is supposed to have a lose relationship with water flow velocity change near the immersion nozzle.

(3) An empirical equation is proposed for the length of the molten mold powder entrapped by the vortex.

(cf. *ISIJ Int.*, **47** (2007), 982)

Molten steel flow control under electromagnetic level accelerator in continuous casting mold

N.KUBO et al.

In a continuous casting process, magnetic coil has been applied to the molten steel flow control in a mold. Some of the magnetic coils are applied to stabilize the molten steel flow and the meniscus fluctuation to prevent powder entrapments. Others are applied to activate the molten steel flow to keep proper temperature at the meniscus or wash inclusions off near the solidification front. The Electromagnetic Level Accelerator (EMLA) has been developed to accelerate the molten steel flow from the nozzle in order to carry the molten steel to the narrow side of the mold when the casting speed is low or the mold width is wide. It applies low frequency alternating magnetic field moving from the nozzle to the narrow side of the mold just below the nozzle exits, because the electromagnetic force acts on the molten steel in the same direction as the magnetic field moving. In this study, the effect of the EMLA on the molten steel flow is investigated. Numerical simulation of the molten steel flow was carried out. The molten steel flow velocity measurement was also conducted in operation.

Applying the EMLA, the molten steel flow is accelerated proportional to the imposed magnetic field. The molten steel flow from the nozzle can be controlled to reach the narrow side of the mold. Therefore, the risk of the extraordinary temperature drop at the mold corner of the meniscus decreases and the capture of the inclusions into the solidification shell that causes the surface defects is avoidable.

(cf. *ISIJ Int.*, **47** (2007), 988)

Forming Processing and Thermomechanical Treatment

Contact element method with two relative coordinates and its application to prediction of strip profile of a sendzimir mill

H.YU et al.

A new numerical method, Contact Element Method with Two Relative Coordinates, has been developed. The main features of this method are that element meshing depends on the contact length between rolls or between the work roll and the strip, and that each element has two relative coordinates based on two separate contact objects. With this method, a program code "Setup Models for Sendzimir Mill" (SM4SM) has been developed for prediction of the strip profile of a 20-high Sendzimir mill with double AS-U-Roll systems. The strip profiles are predicted under various rolling conditions, such as the positions of AS-U racks, the 1st intermediate roll (IMR) shift and taper slope & length, the roll J profile and the coefficient of friction, *etc.*

(cf. *ISIJ Int.*, **47** (2007), 996)

Experimental and semi-analytical study of wear contour of roll groove and its applications to rod mill

S.-M.BYON et al.

In this study, we propose a semi-analytical model which predicts the wear contour of grooved roll in the oval–round (or round–oval) pass rolling process. In the proposed model, the wear contour is assumed to be of a second order polynomial function and computed by using the linear interpolation of the radius of curvature of an incoming workpiece, that of roll groove and a weighting function which takes into account roll force, longitudinal contact length of work roll that undergoes during rolling, property of work roll and roll tonnage. The validity of the proposed model has been examined by applying it to the roughing train in the POSCO No. 2 Rod Mill.

A wear measurement system of roll groove has also been developed. Roll wear contour was measured using 'resin plastics' which can flow, under small external load, without restraint into any region worn out. The deformed resin plastics, *i.e.*, roll wear contour, was measured.

Results show the proposed model in this study, in overall, has a reasonable accuracy in predicting the roll wear contour but the model underestimates slightly the measurements as the roll speed increases. Roll wear has been found to be linearly dependent on the longitudinal contact length of work roll, roll tonnage, but non-linearly on the roll force and inverse proportional to hardness of work roll.

(cf. *ISIJ Int.*, **47** (2007), 1006)

Surface Treatment and Corrosion

Effects of heat treatment conditions on formation of Fe–Al alloy layer during high temperature aluminizing

T.SASAKI et al.

Diffusion couples of Fe_2Al_5 and various substrates with different carbon content, pure iron, 0.27 mass% C steel and 0.45 mass% C steel were processed, and the formation of an Fe–Al alloy layer in the temperature range from 750 to 1 000°C was investigated. $FeAl_2$, FeAl, and aluminum solid solution (αFe(Al)) were confirmed in the alloy layer formed by heating the diffusion couples. Voids were generated inside the Fe_2Al_5 layer and near the interface between the FeAl layer and αFe(Al) layer. The layer growth of FeAl and αFe(Al) obeyed the parabolic law of the diffusion time, $t^{1/2}$. However, the thickness of FeAl saturated over a diffusion time longer than 3.6 ks at 950°C because of the concentration of voids at the FeAl layer/αFe(Al) layer interface and the disappearance of the Fe_2Al_5 layer. The activation energy for the formation of the FeAl layer in all kinds of the substrates was approximately 200 kJ/mol in the whole temperature range and the substrate. On the other hand, the activation energies for the αFe(Al) layer in the 0.27 mass% C steel and the 0.45 mass% C steel were larger than that in pure iron at 750–800°C.

(cf. *ISIJ Int.*, **47** (2007), 1016)

Biocorrosion of low alloy steel by *Desulfotomaculum* sp. and effect of biocides on corrosion control

D.ÇETİN et al.

In this study corrosion behavior of low alloy steel was investigated in the presence of anaerobic sulfate-reducing *Desulfotomaculum* sp. which was isolated from an oil production well. In order to determine corrosion rates, mass loss measurements were performed with and without bacteria in the culture medium. Scanning electron microscopic observations and energy dispersive X-ray spectra analysis were made on steel coupons.

The influences of different concentrations of two biocides (formaldehyde and glutaraldehyde) on corrosion behavior and growth of *Desulfotomaculum* sp. were determined. Formaldehyde was found to be more potent under experimental conditions.

(cf. *ISIJ Int.*, **47** (2007), 1023)

Codeposition behavior of impurities during electrogalvanization in sulfate baths in the presence of Fe ions

H.NAKANO et al.

The codeposition behavior of impurity Fe with Zn was investigated galvanostatically over the current density range 1–1000 A/m^2 at 40°C in zinc sulfate solutions of pH 3 containing 5 000 ppm of Fe^{2+} and other organic or inorganic impurities. Fe showed hardly any codeposition with Zn in solutions containing Fe and either Mo or Ni as impurities. The codeposition of Fe is strongly suppressed in the presence of Zn^{2+} ions through preferential adsorption of Zn hydroxide on the cathode. In solutions containing Fe and Cu, Fe codeposited with Zn and the Fe content in the deposit decreased with increasing current density. Codeposited Cu promotes Fe deposition by providing active sites that are free of adsorbed Zn hydroxide. In solutions containing Fe and benzyl(dimethyl)(stearyl)ammonium chloride (C18-Benzyl) as an impurity, significant amounts of Fe were codeposited. The cathode potential for Zn deposition was greatly polarized by addition of C18-Benzyl, and the Fe content in deposits increased with increasing current density.

(cf. *ISIJ Int.*, **47** (2007), 1029)

Transformations and Microstructures

The effects of heating rate on austenite grain growth in a Ti-modified SAE 8620 steel with controlled niobium additions

K.A.ALOGAB et al.

The effects of heating rate on austenite grain growth and precipitate distribution in Ti-modified SAE 8620 steels with Nb additions of 0.02, 0.06 and 0.1 wt% were evaluated with pseudo-carburizing, *i.e.* without a carburizing gas, heat treatments char-

acteristic of high temperature vacuum carburizing. Laboratory plates were produced to simulate conventional hot-rolling and controlled-rolling processes. Specimens were heated at rates between 10 and 145°C min^{-1} to 1 050 and 1 100°C, held at the desired austenitizing (carburizing) temperature for 60 min, and immediately quenched in iced-water. Austenite grain structures developed at the austenitizing temperatures were evaluated with light optical metallography, and precipitate dispersions were evaluated using extraction replicas in the transmission electron microscope. Abnormal grain growth was observed in all samples processed at the highest heating rate to 1 050°C, but was suppressed at the lower heating rates with additions of 0.06 and 0.1 Nb. Suppression of abnormal grain growth was correlated with the development of a critical distribution of fine NbC precipitates, stable at the austenitizing temperature. The importance to industrial carburizing practice of heating rate effects on precipitates and austenite grain size evolution are discussed.

(cf. *ISIJ Int.*, **47** (2007), 1034)

Variations in the microstructure and hardness with solution treating and aging conditions in new $\alpha+\beta$ titanium alloy Ti–4.5%Al–6%Nb–2%Fe–2%Mo

T.HIRANO et al.

Variations in the microstructure and hardness with solution treating and aging conditions in new $\alpha+\beta$ titanium alloy Ti–4.5%Al–6%Nb–2%Fe–2%Mo were investigated. Solution treating (ST) temperatures were varied from 1 048 to 1 173 K with both cooling conditions of water quenching and air cooling. Cooling rate after solution treating was varied from 1 to 60 K/s using a hot working simulator. Age-hardening was investigated at temperatures ranged from 573 to 823 K and aging time periods were varied in the range from 0.36 to 32.4 ks. An extremely fine two-phase microstructure with α grain size of around 1 μm was obtained at ST temperature of 1 048 K. The large amount of retained β phase was obtained by solution treating at temperatures below 1 098 K, and the amounts of α'' martensite and athermal ω phase increased with an elevation of ST temperature above 1 098 K. For solution treating with water quenching, no hardness variation with solution treating temperature was observed. Age-hardening at the temperatures above 723 K took place at an extremely short aging time. Peak-age was observed in such a short aging time period as 0.36 ks, and hardness value at peak-age increased markedly and continuously with an elevation of solution treating temperature. Age-hardening was confirmed to be caused by very fine a precipitates, and age-hardening behavior noted above was explained by athermal ω phase playing a role of a nucleus for a precipitate.

(cf. *ISIJ Int.*, **47** (2007), 1041)

Microstructural investigation on a medieval sword produced in 12th century A.D.

C.MAPELLI et al.

The construction of sword during the medieval age reaches a good level of quality in the western world where the "Damascus" swords assumes a legendary fame. Even from the ancient times two types of "Damascus" swords have been known: the eastern type based on the application of the ipereuctoid steels and the Western Damascus or Welded Damascus, because obtained through the friction welding of thin strips featured by different carbon contents. In this study a sword found in 1948 on the Adige riverside, near Legnago, has been sectioned and examined by optical microscopy, SEM-EDS, SEM-EBSD and the micro-hardness Vickers testing in order to point out the main microstructural features of the welded system, to identify the chemical composition of the non-metallic inclusions and the crystallographic textures produced by the forging operation. The obtained results have permitted to formulate plausible hypothesis about the significant aspects of the production process: temperature of the ore reducing furnace and of the thermo-mechanical route followed by the ancient artisans.

(cf. *ISIJ Int.*, **47** (2007), 1049)

Mechanical Properties

Effect of martensite on the mechanical behavior of ferrite–bainite dual phase steels

A.SAHA PODDER et al.

This paper reports study on correlations obtained between the microstructure and mechanical properties of four hot rolled ferrite–bainite dual phase steels containing 2–6% of martensite phase. It has been observed in these steels that a small amount of martensite (2% and above) is adequate to produce the continuous yielding behavior, characteristic of conventional dual phase steels. These dual phase steel contain substantial amounts of bainite (47 to 74%) and can achieve high mechanical strength coupled with adequate ductility. The value of the strain hardening exponents of such steels is however rather low. The addition of substitutional alloying elements such as Cr, Mo or V has been found to increase significantly the strength levels of such steels over that of the C–Mn–Si base composition.

(cf. *ISIJ Int.*, **47** (2007), 1057)

Social and Environmental Engineering

Accounting for steel stock in Japan

I.DAIGO et al.

During the last two decades, the total material input in Japan has been about 2 billion tons per year, and approximately 50%, *i.e.*, about 1 billion tons, has accumulated as the net addition to stock in the form of buildings, social infrastructure, and various kinds of products. The amount of the net addition to stock is calculated annually from the differential between the input and output. However, the detailed contents of the accumulated stock are unknown. It is said that these unknown contents of stocks include material that has already been discarded as invisible waste. In this study, the following terms are defined: in-use stocks, obsolete stocks, and overall stocks. The materials that are currently used in society are known as "in-use stocks". Obsolete stocks comprise the steels used for the constructional material in a landfill site, the steels dissipated by corrosion and erosion, *etc.*, which are not associated with social activities and cannot possibly be collected as scrap in the future. Overall stocks are the total of these two types of stock. In this study, a dynamic material flow analysis was conducted to quantify the amount of in-use stocks and obsolete stocks. Furthermore, we defined a system boundary to account for the steel stocks and constructed equations to calculate the three types of stock. The amounts of in-use stock and obsolete stock in Japan from 1980 to 2000 were calculated. The result shows that 0.94 billion tons of the in-use stock is included in the 1.22 billion tons of overall stock in the year 2000.

(cf. *ISIJ Int.*, **47** (2007), 1064)