（＊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

Prediction of phase separation in silicate glass for the creation of value-added materials from waste slag

M.SUZUKI et al.

A thermodynamic evaluation was performed to predict phase separation in multi-componentoxide glasses. Composition ranges for metastable liuid–liquid immiscibility and spinodal decomposition in a SiO_2–CaO–MgO–Na_2O quaternary system were calculated on the assumption that glasses in the oxide system can be regarded as super-cooled liquid phases. Some experimental studies on two-phase separation of glasses were carried out to confirm the thermodynamic evaluation of the phase separation. Microstructures in heat-treated glass samples were observed by transmission electron microscopy, to investigate the development of interconnected microstructures in the glass with increased heating temperatures and holding times, and spinodal decomposition of glass was indicated.

(cf. *ISIJ Int.*, **46** (2006), 1391)

Ironmaking

Optimum coke-free space volume in blast furnace hearth by wall shear stress analysis

B.DESAI et al.

Conservation equations of mass and momentum are solved numerically in an actual plant size hearth to determine the wall shear stress at various operating conditions. The effect of different coke-bed shape and position was studied on the wall shear stress of the hearth. It was found that there exists an optimum coke-free space volume for all kinds of coke-bed shapes with respect to shear stresses on the sidewall as well as on the hearth bottom. It was found that conical coke-bed with a sitting position could induce more wall shear stress on the side wall if the coke-free space volume was limited to about 48 m^3 and if the free space increased beyond 48 m^3 then the spherical coke-bed in a floating condition induced maximum stress on the wall where as all other coke-bed shapes studied were benign to the stress on the wall. Conical coke-bed shape is more vulnerable, in terms of producing more stress on the hearth bottom than any other shapes.

(cf. *ISIJ Int.*, **46** (2006), 1396)

Production of pig iron from magnetite ore–coal composite pellets by microwave heating

K.ISHIZAKI et al.

Magnetite ore–coal composite pellets with about 10, 15 and 20 mm diameter were rapidly smelted to produce pig iron by microwave heating in N_2 gas. A microwave generator with 5 kW maximum power at 2.45 GHz was employed. Carbon content in pig iron was about 2 mass% near the liquidus line in the Fe–C system. Slag was easily separated from pig iron. By XRD analysis it is realized that the reduction of magnetite started at about 800°C and was completed to be pig iron at about 1 350°C. The heating rate of pellets was independent of their mass but dependent on applied power because of self heating. According to the increase of heating rate, the level of impurities in pig iron decreased less than blast furnace.

(cf. *ISIJ Int.*, **46** (2006), 1403)

The temperature field digitization of radiation images in blast furnace raceway

S.ZHANG et al.

This article applies digital image processing techniques to the research for the algorithm of peep-temperature-field of flame image. Embarking on the factors which produce errors, the traditional bicolorimetric temperature measurement method is obtained proofreading. Then this algorithm is applied to the research on establishment of the temperature fields for gas combustion flame image in the small experiment table as well as radiative image in blast furnace raceway in some steel corporation. By the laboratory research we obtain that coefficient of correction equals to 33.4 and error value between the measured temperature and calculated temperature is in the scope of 5.0%. The result shows that the temperature fields of gas combustion flame image and those of radiative image in raceway reflect accurately the actual temperatures respectively as well as a series of changes for flame temperature information caused by varying working conditions. Therefore, it lays foundations for furnace operators to provide visualized image information and accurate temperature information.

(cf. *ISIJ Int.*, **46** (2006), 1410)

Casting and Solidification

Simple tundish mixing model of continuous casting during a grade transition

M.J.CHO et al.

A novel tundish mixing model is proposed to predict the outlet concentration of the tundish during a grade transition. To enhance the efficiency and replication performance, the present model was designed to minimize the number of parameters to only one that needs to be tuned for easier application to new situations whereas the Huang and Thomas model has six parameters to be tuned. Two types of water model were employed to verify the present model, and the real grade mixed blooms were produced through a grade transition continuous casting. When the present tundish mixing model was applied to the cases of the water models and real bloom casting, the numerical results of the present model were found to be in good agreement of the experimental data, and the constant parameter f of the present model was found to be determined according to the tundish shape.

(cf. *ISIJ Int.*, **46** (2006), 1416)

Influence of casting speed variation during unsteady continuous casting on non-metallic inclusions in IF steel slabs

Q.ZHANG et al.

The influence of casting speed variation on non-metallic inclusions in surface layers of IF steel slabs during continuous casting were investigated with OPA (Original Position Statistic Distribution Analysis) method. It was found that, when the casting speed was evenly decreased from 1.4 to 0.6 m/min, increases of the nonmetallic inclusions owing to the increase of the mold powder entrapment were observed only on those slabs which were cast at the start of casting speed change. While, in experiment of increasing casting speed evenly from 0.6 to 1.4 m/min, increases of nonmetallic inclusions were observed only on slabs which are cast at the time when the casting speed was stopped to increase after it had been increased to 1.4 m/min. For slabs which were cast during the casting speed evenly increasing or decreasing period and at the time when increasing or decreasing the casting speed at low casting speed level (0.6 m/min), the influence of casting speed change was very small. In addition, it was found that, at high casting speed level (1.4 m/min), even a little change of casting speed could result in remarkable increase of the non-metallic inclusions. Thus, at high casting speed, changing casting speed should be avoided or using much slower speed changing rate.

(cf. *ISIJ Int.*, **46** (2006), 1421)

The effect of oxygen partial pressure on heat transfer and solidification

Y.YU et al.

The effect of oxygen partial pressure (P_{O_2}) in different gas atmospheres on heat transfer, cast structure and secondary dendrite arm spacing in droplet solidification process has been investigated. It has been found that the P_{O_2} of the gas affects solidification process and undercooling. As P_{O_2} decreases, at relatively high P_{O_2} ($10^{-1.2}$–10^{-4}) in 99.99% Ar and air atmosphere, heat flux is decreased and equiaxed zone ratio and secondary arm spacing are found to be increased. At intermediate P_{O_2} (10^{-14} to 10^{-20}) in Ar–H_2 atmospheres, heat flux and equiaxed zone ratio varies only slightly and secondary arm spacing is reduced. At low P_{O_2} (10^{-20}–10^{-23}) in Ar–5%H_2 atmosphere, heat flux increases dramatically and the equiaxed zone ratio and secondary arm spacing are reduced. The largest equiaxed zone is found with intermediate P_{O_2} levels in Ar–H_2 gas atmospheres, whereas the finest grains are obtained in Ar–5%H_2 gas in low P_{O_2} value.

(cf. *ISIJ Int.*, **46** (2006), 1427)

Cold model experiment on infiltration of mould flux in continuous casting of steel: simulation of mould oscillation

T.KAJITANI et al.

For mould flux infiltration in an oscillating mould, we develop a new cold model experiment in which silicone oil is infiltrated down between a moving belt and an acrylic plate. The apparatus is designed on the basis of the following concepts:

(1) The film thickness of liquid flux channel is varied during mould oscillation with the balance between the pressure in the flux channel and static pressure in the molten steel pool.

(2) The flux channel has a profile that it becomes wider along casting direction.

For this purpose, the film thickness of the infiltrating oil, which can be changed by the oscillating motion of the belt, is directly measured employing a linear gauge sensor.

The experiment reveals that the film thickness is increased during the upward motion of the belt and is decreased during the downward motion. Using the measured film thickness, a theoretical model calculates infiltration rate of the oil that corresponds to mould flux consumption in casting operation. It successfully reproduces the empirical observation that mould flux consumption decreases with increasing casting velocity, flux viscosity or oscillating frequency. Those results provide a new mechanism of mould flux infiltration, where the flux is infiltrated down from the last stage of positive strip time until the latter half of negative strip time. In this period, the downward motion of the mould and strand draws the flux down through the channel that has been widen by the preceding upward stroke of the mould.

(cf. *ISIJ Int.*, **46** (2006), 1432)

Instrumentation, Control and System Engineering

Synthesis method for the modelling and robust control of coating weight at galvanizing process

K.Shin et al.

In this paper, we propose a new practical synthesis model for coating weight control and robust design method of feedback controller in galvanizing process. Firstly, we propose a new model, which combines both long term and short term model. Long term model has a good accuracy to predict the next distance and pressure of air knife for wide range of target coating weight, because it has the functions of classification, averaging and learning based on real measured data. Short term model has variational form based on linear change of inputs and outputs and is used at all controls except preset control. Based on this model, we propose a set of practical controller and a robust design method of feedback controller so that it can attenuate quickly the errors caused by time-delay and modelling error. The proposed model with controller were applied to continuous galvanizing line (CGL) at Kwang Yang Steel Works and we obtained good experimental results on the deviation control of coating weight at top of coil and uniform coating weight on the surface of strip.

(cf. *ISIJ Int.*, **46** (2006), 1442)

Chemical and Physical Analysis

The surface segregation of copper in non-oriented electrical steels

D.Steiner Petrovič et al.

The surface segregation of copper was investigated in laboratory and industrial non-oriented electrical steel sheets containing copper. The cold-rolled samples of Fe–Si–Al alloys were annealed in the temperature range 320–1 120 K in the ultra-high-vacuum chamber of a field-emission Auger electron spectrometer, and subsequently characterized by Auger electron spectroscopy (AES).

The Cu segregation rate was estimated based on the surface concentration of Cu after annealing at a given temperature. Not surprisingly, the AES analysis showed that the intensity of the surface segregation of copper increased with increasing annealing temperature. However, thermal desorption spectroscopy (TDS) showed that above 770 K the desorption of Cu started to reduce the surface concentration of Cu, thus making a reliable estimation of the segregation rate impossible.

During the annealings, in addition to the surface segregation of copper, the surface segregation of alloying and impurity elements was observed as well. Moreover, it appeared that some of these constituents compete for available surface sites. For example, it could be concluded that the surface segregation of copper hindered the surface segregation of carbon in the Fe–Si–Al alloys.

(cf. *ISIJ Int.*, **46** (2006), 1452)

Forming Processing and Thermomechanical Treatment

A new analytical model for the calculation of mean roll radius in round-oval-round alloy bar rolling

Y.Dong et al.

In rod (or bar) rolling process, the roll surface is not flat for the groove on the roll, so the roll radius is not constant along the roll axis direction. In this paper, a suitable spread formula was determined to calculate the maximum spread of alloyed steel, then the surface profile of outgoing workpiece and the critical point on the contact boundary has been predicted. Furthermore, the formula of the equivalent contact section area has been proposed and the mean roll radius has been obtained.

The validity of the new model has been examined by the bar rolling experiment and the rigid-plastic FEM simulation. Compared with the existing models, the mean roll radius obtained by the new analytical model approach the experiment data more closer than other models. So, it can be used as a available reference in practice and the theoretical derivation.

(cf. *ISIJ Int.*, **46** (2006), 1458)

Surface Treatment and Corrosion

Corrosion resistance of Cr-bearing rebar in macrocell corrosion environments due to different concentrations of chloride ions

S.-H.Tae et al.

Reinforced concrete specimens were prepared by embedding 10 types of Cr-bearing reinforcing bars having different Cr contents and supplying saltwater from the upper surfaces to allow chloride ions to penetrate into concrete, thereby forming macrocells, with the aim of developing Cr-bearing rebars having corrosion-preventing properties required under macrocell-corrosion conditions due to differences in the chloride concentrations. The time-related changes in the macrocell corrosion current density, soluble chloride ion content of concrete, and half-cell potential were then measured during corrosion-accelerating test up to eight months. Also, the corrosion area and corrosion loss of anodic and cathodic bars were measured at the end of the 8-month corrosion-accelerating test to investigate the corrosion-inhibiting property of Cr-bearing rebars in macrocell corrosion environments due to chloride ion concentration in concrete.

As a result, the Cr content required for corrosion inhibition was found to be more than 7% in macrocell corrosion environments with a difference in soluble chloride ion concentrations of not more than 2.4 kg/m^3.

(cf. *ISIJ Int.*, **46** (2006), 1467)

Investigations on the abrasive wear behaviour of flame sprayed Ni–Cr–Co–Si alloy coating deposited on mild steel substrate

S.Harsha et al.

In present paper the influence of the post spray heat treatment on microstructure, microhardness and abrasive wear behaviour of flame sprayed Ni–Cr alloy (EWAC 1004) coatings deposited on mild steel has been reported. Coatings were deposited by oxy-acetylene flame spraying torch. The post spray heat treatment of the coatings was done at 800°C for 2 h. Wear behaviour of coatings was evaluated using pin on disc wear system against 120 and 600 grades SiC abrasive medium at 5 N, 10 N, 15 N and 20 N normal load. Results showed that the influence of normal load on wear rate is governed by the microstructure, hardness and abrasive grit size. Heat treatment increased average microhardness of the coating. Heat treatment of these coating deteriorated the abrasive wear resistance against both fine and coarse abrasive mediums. In general, increase of normal load increased the wear rate. SEM study showed that wear is largely taken place by plowing, microcutting and crater formation mechanisms.

(cf. *ISIJ Int.*, **46** (2006), 1473)

Transformations and Microstructures

Design of advanced bainitic steels by optimisation of TTT diagrams and T_0 curves

F.G.Caballero et al.

Cementite is responsible of the limited application of conventional bainitic steels, however it has been proof that cementite precipitation during bainite formation can be suppressed by the judicious use of silicon in medium carbon steels. In this work, thermodynamic and kinetic models were used to design steels with an optimum bainitic microstructure consisting of a mixture of bainitic ferrite, carbon-enriched retained austenite and some martensite. Using these models, a set of seven carbide free bainitic steels with a 0.3 wt% carbon content were proposed for manufacturing. The work presented here is concerned with the microstructural and mechanical characterisation of the steels manufactured. Except for the steel with the highest content of alloying elements, all the grades present the same microstructure composed of carbide-free upper bainite and retained austenite after hot rolling and a two-steps cooling. Theirs tensile strengths range from 1 600 to 1 950 MPa while keeping a uniform elongation equal to 4% and a total elongation over 10%.

Regarding toughness at room temperature, they match quenched and tempered martensitic steels.

(cf. *ISIJ Int.*, **46** (2006), 1479)

Phase transformations in two C–Mn–Si–Cr dual phase steels

A.MURUGAIYAN et al.

The continuous cooling transformation behaviour of dual phase steels were studied with emphasis on the effects of addition of chromium, cooling rate and intercritical annealing temperature on the volume fractions of different transformed products of austenite. The results show that addition of 0.21 % chromium promotes the formation of acicular products in the final microstructure and does not have much effect on the volume fractions of the co-existing phases at intercritical annealing temperatures. A mathematical model based on Avrami's equation and Scheil's additivity principle was developed to predict the volume fractions of polygonal ferrite as a function of cooling rate for one of the continuous cooled steels. The predicted results from the model show good agreement with experimental observations.

(cf. *ISIJ Int.*, **46** (2006), 1489)

Shear band thickening during rolling of interstitial free steel

M.Z.QUADIR et al.

This paper shows how shear bands which are produced by slip, and are initially of the width of microbands in interstitial free (IF) steel, thicken to the order of 5–7 times the thickness of microbands. The process involves the operation of two shear bands shearing in opposite senses. The importance of this process is that it is capable of increasing the misorientation of the shear band material such that in principle, shear bands can provide nuclei for recrystallization. This reconciles the observation that sometimes shear band nucleation is observed, while in others, it does not happen.

(cf. *ISIJ Int.*, **46** (2006), 1495)

The austenite/ferrite front migration rate during heating of IF steel

E.SCHMIDT et al.

The austenitization of interstitial free (IF) steel was investigated through real time imaging of evolving surface relief structures through a hot-stage confocal scanning laser microscopy. Nucleation was observed at grain edges but site saturation did not occur. As expected the, the migration rate was found to be controlled by an interface reaction and the rate was, within the experimental errors, nearly indistinguishable between IF steels, pure Fe and previously reported rates for pure Fe with activation energies between 174–180 kJ/mol. There was no apparent effect of solute drag caused by the trace solute elements in the IF steel, but the non-metallic oxide and nitride particles present in the IF steel appeared to impede the front migration and caused it to become jagged in appearance.

(cf. *ISIJ Int.*, **46** (2006), 1500)

Mechanical Properties

Effects of microalloying elements on mechanical properties of reinforcing bars

S.HASHIMOTO et al.

Reinforcing steel bars are an important material for construction. The strength level of rebar has been increased to as high as, for example, 345, 390 and 490 grade. In order to produce high-strength rebar, V microalloying technology has been successfully applied, while Nb application to reinforcing bars has been tried energetically recently. However, exact discussions about the effect of hot-rolling and cooling condition in Nb microalloyed steel on mechanical properties have not been reported exactly.

This paper reports on the experimental results of the effects of reheating temperature and cooling rate after hot-rolling on the microstructure and mechanical properties of 0.25C–0.5Si–1.2Mn steel and 0.25C–0.5Si–1.2Mn–0.05Nb(+0.05V) steel (mass%).

0.05% Nb and 0.05% Nb+0.05% V additions to 0.25C–0.5Si–1.2Mn steel (mass%) led to an effective increase in strength, especially at high reheating temperature. This strengthening is caused by precipitation hardening and grain refinement hardening. Accelerated cooling after hot-rolling to 700°C was effective in increasing strength and yield point elongation.

(cf. *ISIJ Int.*, **46** (2006), 1510)

Creep fracture mechanism map and creep damage of Cr–Mo–V turbine rotor steel

N.SHINYA et al.

Specimens of a Cr–Mo–V rotor steel with creep rupture lives of up to 100 000 h were examined metallographically to clarify their creep fracture mechanisms and to construct creep fracture mechanism maps showing the dominant regions of each mechanism. The creep fracture mechanism maps were constructed with stress on the y-axis and time to rupture on the x-axis, and also with stress on the y-axis and testing temperature on the x-axis. The maps included three different creep fracture mechanism fields: transgranular creep fracture, intergranular creep fracture with cavitation, and rupture with dynamic recrystallization. The maps indicate that the steel in the service of power plants is being used under conditions within the field of intergranular creep fracture with cavitation. This means that long term use of this steel under the conditions could cause extensive cavitation and low ductility fracture due to the cavitation.

(cf. *ISIJ Int.*, **46** (2006), 1516)

Physical Properties

An *ab initio* study of the energetics for interfaces between group V transition metal carbides and bcc iron

S.-H.CHUNG et al.

An *ab initio* study was carried out on interface energies, misfit strain energies, and electron structures at coherent interfaces between bcc Fe and MCs (NaCl structure, M=V, Nb, Ta). The interface energies at relaxed interfaces Fe/VC, Fe/NbC, and Fe/TaC were −0.120, −0.169 and −0.158 J/m^2, respectively. Influence of bond energy was estimated using the discrete lattice plane/nearest neighbor broken bond (DLP/NNBB) model. It was found that the dependence of interface energy on the type of carbide was closely related to changes of the bond energies between Fe, M and C atoms before and after formation of the interfaces Fe/MC. The misfit strain energies in Fe/VC, Fe/NbC, and Fe/TaC systems were 0.086, 0.891 and 0.827 eV per 16 atoms (Fe; 8 atoms and MC; 8 atoms), respectively. The misfit strain energy became larger when difference of lattice parameters between the bulk Fe and the bulk MCs increased.

(cf. *ISIJ Int.*, **46** (2006), 1523)