（＊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

Refining behaviors in the fractional melting process

K.W.KIM et al.

Fractional melting process involves heating an alloy within its liquid–solid region simultaneously ejecting liquid from the solid–liquid mixture. The extent of the purification obtained is comparable to that obtained in multi-pass zone refining. The fractional melting process in which the centrifugal force was used for separating the liquid from the mixture has been developed. The refining behaviors of the present F.M. process were analyzed quantitatively using the new parameter called "the refining partition coefficient, k'". The effects of the process parameters such as a rotating speed and a heating rate on the coefficient, k' and the refining behaviors were also studied.

(cf. *ISIJ Int.*, **40** (2000), 419)

Carbon dissolution behaviors in MO(M=Ca, Ba)–B_2O_3 slags

S.-H.KIM et al.

Carbon is known to dissolve into slag as carbide ion (C_2^{2-}) under a low oxygen partial pressure. In order to clarify these mechanisms of carbon dissolution, carbon solubility was measured both in acidic and basic slags under various oxygen partial pressures and temperatures. In basic slags, carbon solubility in MO(M=Ca, Ba)–B_2O_3 slags decreased with increasing the oxygen partial pressure and increased with increasing basicity confirming the carbide ion formation mechanism. But in acidic slags, carbon solubility in MO(M=Ca, Ba)–B_2O_3 slags decreased with increasing basicity and oxygen partial pressure. In order to explain these phenomena, the probable mechanism was discussed and suggested on the basis of experimental results. The model of nitrogen dissolution into slag was compared to that of carbon dissolution to find similar effects of basicity on the dissolution behaviors.

(cf. *ISIJ Int.*, **40** (2000), 425)

Suppression of slag foaming under sound wave application

S.V.KOMAROV et al.

High temperature experiments have been conducted to examine a possibility of suppression of slag foaming by applying sound waves. To produce the slag foam, Ar gas was injected into a BaO–B_2O_3 or a CaO–SiO_2–FeO melt through a submerged multihole nozzle or a bottom nozzle. The sound waves, produced by a loudspeaker, were propagated to the foamed slag surface through the gas atmosphere inside the experimental apparatus. The experimental temperatures were 1 223 and 1 273 K (BaO–B_2O_3 slag), and 1 573 K (CaO–SiO_2–FeO slag).

Main attention was focused on the effect of sound frequency on slag foaming rate. It was found that the slag foaming rate is significantly decreased on frequencies 200 and 350 Hz (slag BaO–B_2O_3), 400 Hz (slag CaO–SiO_2–FeO) and 10 000 Hz (slag BaO–B_2O_3). On the whole, low frequency (<1 000 Hz) is more effective in suppressing the foaming slags. The frequency dependence of the slag foaming rate is explained by resonance oscillations which can occur in the working space of the experimental apparatus at certain frequencies.

To evaluate the thickness of foam film, measurements of steady foam height and radius of bubbles detached from the nozzle were made. On the basis of the results, it was shown that low frequency can pass through the foam layer and excite the foam bubble oscillations. This is assumed to result in an enhanced drainage of liquid from the foam layer to the molten bath. On the other hand, when foaming slag surface is exposed to higher frequency sound waves, they are completely reflected from the surface, and the foam breakage occurs due to increase in the foam film rupture rate.

(cf. *ISIJ Int.*, **40** (2000), 431)

Ironmaking

Model of the state of the blast furnace hearth

J.TORRKULLA et al.

A model for estimation of erosion and skull profiles of the blast furnace hearth is presented. The model, which is based on thermocouple measurements in the hearth bottom and wall lining, estimates the most severe erosion of the lining experienced during the campaign and also the present thickness of the skull material. The model is illustrated on process data from two Finnish blast furnaces. Complementary measurements and calculations are used to verify the results. Based on the findings, conclusions are drawn about the internal state of the blast furnace hearth, for instance, whether the dead man floats or sits at the bottom. Finally, some suggestions on how to control the state of the furnace hearth are given.

(cf. *ISIJ Int.*, **40** (2000), 438)

Numerical simulation model of the iron ore sintering process directly describing the agglomeration phenomenon of granules in the packed bed

M.V.RAMOS et al.

Comprehensive numerical simulation model was developed to describe the structural changes in the iron ore sintering bed by using the discrete element method (DEM). The heat wave propagation through the sintering bed was incorporated by combining the solutions of the various reaction rates and gas–granule heat transfer with the calculation of the granule movement by DEM. Simulations were conducted under different conditions, *i.e.*, different carbon content and melting temperature of the granules. Results show that both carbon content and melting temperature of the granule influence the final structure of the sintering bed. The obtained structural change of the sintering bed show that the proposed model is a potential tool to analyse the agglomeration phenomena occurring in the iron ore sintering process under various conditions.

(cf. *ISIJ Int.*, **40** (2000), 448)

Steelmaking

Development of a novel degassing process with single large immersion snorkel and a bottom bubbling ladle

S.KITAMURA et al.

A novel vacuum degassing process consisting of a large immersion snorkel and a bottom bubbling ladle has been invented for the efficient production of ultra-low carbon steel. This process has been confirmed by industrial scale test using 175 and 350 t ladle and named REDA (Revolutionary degassing activator). The carbon content reaches 10 ppm in 15 to 20 min treatment, and decreases to 4 ppm without any stagnation. As REDA has a wide bubble activated surface area and a deep injection position, relatively low gas flow rate is necessary to produce ultra-low carbon steel efficiently.

(cf. *ISIJ Int.*, **40** (2000), 455)

Casting and Solidification

Modelling of a novel configuration for single-belt caster: the influence of empirical parameters on the solidification profile

P.G.Q.NETTO et al.

A mathematical model was developed to simulate fluid flow/heat transfer phenomena in a proposed configuration for a single-belt caster. The main goal of the research was to evaluate the flow modifications yielded by the insertion of a flow modifier in the computational domain. This paper deals in particular with the influence of some empirical parameters in the model predictions.The most important inputs for the mathematical model were found to be the interfacial heat transfer coefficient h and the morphology constant C. These two parameters, in addition to the numerical treatment for turbulence, had a remarkable influence on the model's outputs. A very high value of C generates strong dampening of velocities within the interdendritic, mushy zone. This leads to predictions of premature solid shell growth within the extended metal delivery zone, leading to too thick a solid shell and too thin a mushy zone at the end of the computational domain. As for the instantaneous heat transfer coefficient, h, an attempt was made to predict its transient characteristics using an experimental simulator. This equipment mimics metal deposition on a substrate moving at the same velocity as an industrial belt (~0.5–1 m/s). Comparisons of predictions made on the basis of different schemes for the variation in h are reported. The importance of an accurate prediction for the way h varies, in terms of the belt's required cooling length, is stressed.

(cf. *ISIJ Int.*, **40** (2000), 460)

Speed disturbance compensation in the secondary cooling zone in continuous casting

F.R.C.CALZOLARI et al.

The continuous casting process is used for the solidification of molten steel into semi-finished shapes. Several factors influence the quality of cast steel, including mould level oscillation and cooling

patterns in the secondary cooling zone. This article presents a dynamic model that can be used to study heat transfer in the continuous casting process. Temperature measurements in the secondary cooling zone are infeasible due to the effects of scale and steam on the measurement equipment. Two different feedforward controllers are proposed and compared to eliminate the effects of varying casting speed on the strand temperature; thus reducing the defects in the finished product. The first controller is based on typical controllers found in practice and a design methodology is proposed for the design of this controller. The second controller has dynamic properties and makes full use of the plant and disturbance transfer functions in its design. It is shown that disturbance rejection of the second controller is better than that of the first controller.

(cf. *ISIJ Int.*, **40** (2000), 469)

Forming Processing and Thermomechanical Treatment

Processing nickel free high nitrogen austenitic stainless steels through conventional electroslag remelting process

G.BALACHANDRAN et al.

Nickel free high nitrogen austenitic stainless steels, made through air-induction melting were processed using conventional electroslag remelting (ESR) process without application of nitrogen gas pressure over the melt. It was found possible to retain the high nitrogen contents of the original steel. The loss in nitrogen content during ESR was found to increase with increasing melt rate. Electroslag remelting was carried out on eleven steels with a base composition at around 18wt%Cr–18wt%Mn–0.1 to 0.6wt%C–0.53 to 0.9wt%N. While the air-induction melted steel had extensive porosity, the ESR ingots were all sound and free from porosity. Thus, steels made in any other process route can be successfully remelted using conventional ESR. The cast structure analysis in a typical medium carbon high nitrogen steel showed that Cr and Mn has a tendency for microsegregation. The presence of microsegregation and residual carbides affect the ductility of the cast steel.

(cf. *ISIJ Int.*, **40** (2000), 478)

Surface Treatment and Corrosion

Velocity field measurements of flow inside snout of zinc plating process using a single-frame PIV technique

S.-J.LEE et al.

In the continuous hot-dip galvanizing process of steel strips, the snout has been installed at the entering region of feeding strip into the molten zinc (Zn) pot. However, evaporated Zn particles in the snout cause ash imperfection on the galvanized steel strip surface. In order to resolve this problem, the flow field inside the snout, both on the deoxidization gas flow above the free surface and the molten Zn flow in the Zn pot, has been investigated experientially. For a 1/10 scale water model, flow visualization and PIV (Particle Image Velocimetry) velocity field measurements were carried out at the strip speed $V_S = 1.5$ m/s. Aluminum flakes (1 μm) and atomized olive oil (3 μm) were used as seeding particles to simulate the molten Zn flow and the deoxidization gas flow, respectively.

As a result, the liquid flow in the Zn pot is dominantly influenced by the up-rising flow in diagonal direction caused by the rotating sink roll. For gas flow in front of the strip inside the snout, the large-scale vortex formed by the downward moving strip is dominant. In the rear side of the strip, a counter-clockwise vortex is formed and some of the flow following by the moving strip impinges on the free surface of molten Zn. The liquid flow in front of the strip is governed by the up-rising flow entering the snout, caused by the rotating sink roll. The moving strip affects dominantly the liquid flow behind the strip inside the snout, and large amounts of liquid are entrained and followed the moving strip toward the sink roll. A thin boundary layer is formed on the front side due to the up-rising flow, however, a relatively thick boundary layer is formed in the rear side of the strip. Inside the snout, the deoxidization gas flow above the free surface is much faster than the liquid flow in the Zn pot. More ash imperfections are anticipated on the rear surface of the strip where larger influx flow moves toward the strip in the region near the free surface.

(cf. *ISIJ Int.*, **40** (2000), 484)

Transformations and Microstructures

Influence of mechanical processing and heat treatment on microstructure evolution in nickel free high nitrogen austenitic stainless steels

G.BALACHANDRAN et al.

A series of nickel free high nitrogen austenitic stainless steels were processed by various mechanical processing and heat treatment conditions to study the evolution of microstructure at every stage of processing. About eleven steels varying in composition, especially in terms of carbon contents, were processed through forging, rolling, solution annealing, cold rolling and warm rolling *etc.* The microstructure at every stage of processing was studied. The hot rolled condition, hot rolled and cold rolled condition gave deformation induced fragmented grain structure. The high carbon steels in the hot rolled conditions showed banding and grain boundary carbo-nitride precipitation. There were also intragranular carbide prcipitation in some of the high carbon steels.The solution treated microstructure in all steels showed extensive annealing twins and the lattice parameter increased with carbon and nitrogen contents. Cold rolling followed by solution treatment lead to development of slip lines in the fully austenitic matrix due to strain hardening of the matrix. The 600°C warm rolled condition showed grain boundary carbide precipitation.

(cf. *ISIJ Int.*, **40** (2000), 491)

Mechanical Properties

Influence of thermal and mechanical processing on room temperature mechanical properties of nickel free high nitrogen austenitic stainless steels

G.BALACHANDRAN et al.

Nickel free high nitrogen austenitic stainless steels with a base composition around 18%Cr–18%Mn and varying in C and N contents and processing conditions were evaluated for their mechanical behaviour. A range of mechanical properties from high strengths to ultra high strength levels could be obtained. The steels develop ultra high strength levels in the as-hot worked condition, hot work+cold work condition and solution treated+cold worked conditions. They show high strength levels with very good ductility and impact toughness levels in the solution annealed condition. The Hall–Petch parameters and DBTT obtained in the solution annealed condition were found to be influenced by the carbon content of the steel. The work hardening behaviour of the steels have been examined at various processing conditions. Nitrogen steels with high carbon content show good mechanical properties in the solution treated and subsequently cold rolled conditions. In the as-formed condition, the high carbon steels show inferior ductility due to grain boundary lamellar nitride precipitation.

(cf. *ISIJ Int.*, **40** (2000), 501)

Effect of stress states on creep fracture modes of an austenitic steel with high ductility

L.-B.NIU et al.

Tensile creep rupture tests using smooth specimens and circumferential U-notched specimens having 4 kinds of notch root radius, and torsional creep rupture tests using smooth and circumferential 60° V-notched specimens of SUS310S austenitic steel with high ductility and high metallographical stability, were conducted at 700°C. In tensile creep rupture tests, it was found that as turning into lower stress level the creep fracture mode of smooth specimens changed from ductile transgranular fracture to brittle intergranular fracture. And irrespective of applied stress and notch geometry, the creep fracture mode of all notched specimens showed brittle intergranular fracture mixed with ductile transgranular fracture. While in torsional creep rupture tests, all smooth and notched specimens in the present test range exhibited a ductile fracture of shear type. These creep fracture modes were discussed on the basis of stress states and steady-state creep stress distributions in notch cross sections calculated by finite element method. The results suggested that mean stress promotes the intergranular creep fracture strongly, and that the equivalent stress promotes the nucleation of intergranular cavities but contributes less to their growth.

(cf. *ISIJ Int.*, **40** (2000), 511)

Micromechanism of ductile crack initiation in structural steels based on void nucleation and growth

N.ISHIKAWA et al.

The effect of the specimen geometry and the inclusion content on the critical condition for ductile crack initiation was determined using notched round bar tensile specimens, and the critical void volume fraction and secondary void nucleation effect were investigated using the Gurson–Tvergaard constitutive model. It is shown that the secondary void nucleation from pearlite nodules plays a dominant role in ductile crack initiation, and void nucleation and void growth behavior are strongly affected by the stress triaxiality and the plastic strain. In the large plastic strain and low stress triaxiality region, a large number of secondary voids were nucleated in the early stage of deformation and void volume fraction grew to a critical value in spite of the relatively low void growth rate at low stress triaxiality. On the other hand, in the low plastic strain and high triaxial stress region, void volume can grow rapidly even though the volume of secondary nucleated void was smaller than that of high plastic strain region. Critical void volume fraction decreases largely with increasing in MnS content in the high triaxial stress region; however, the effect of MnS content is small in the low stress triaxiality and large plastic strain region.

(cf. *ISIJ Int.*, **40** (2000), 519)