（＊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

The effect of Fe^{3+} ions on the anionic structure of iron-bearing sodium silicate melts

Y.SASAKI et al.

The effects of the coordination of iron ions on the anionic structure of molten iron bearing sodium silicate slags at 1 273 K have been investigated by Raman spectroscopy. The Raman spectra of Na_2O–SiO_2–FeO–Fe_2O_3 system equilibrated with various oxygen pressures (pO_2) have been measured. The effect of the concentration of iron oxide on the Raman spectra of these systems has also been studied.

Under low pO_2 conditions ($CO_2/CO<10$), the Raman spectra of $Na_2O \cdot 2SiO_2$–FeO–Fe_2O_3 are essentially the same as that of $Na_2O \cdot 2SiO_2$. However, under high pO_2 conditions ($CO_2/CO>54$), a new Raman band of around 900 cm^{-1} appears and its intensity increases with increase of pO_2 and iron oxide content. The scattering intensity at low frequency region (<550 cm^{-1}) also becomes intense with increase of the iron oxide content.

It is confirmed that the near 900 cm^{-1} band can be attributable to the network structure involving Fe^{3+} ions. Fe^{3+} ions in the metasilicate melts is found to conjugate the chain units and produce the sheet and monomer units. In the disilicate melts, it will conjugate the sheet units and produce the chain and three-dimensional network units.

(cf. *ISIJ Int.*, **40** (2000), 1181)

Ironmaking

Improvement of productivity by stand-support sintering in commercial sintering machines

K.HIGUCHI et al.

The sinter cake load on the combustion-melting zone has a great effect on structure formation of sinter cake especially at the lower layer. It increases the permeability resistance of sintering bed due to gas channel plugging and also affects the qualities of the sinter products indirectly.

A new sintering technique, called "Stand-support sintering", for supporting the sinter cake with bars or plates attached to pallets has been developed.

As a result of a pot test, it was found that the stand-support sintering sharply shortened the sintering time. Further, productivity was improved by nearly 20%. This technique was applied to the sintering machines at Kimitsu works. Nearly homogenous sinter cake support was obtained when the stands were properly arranged in pallets to make shrinkage and gas flow rate of sintering bed constant in the width and strand directions at the commercial plant. As a result of an operation test with the low stands and the high stands, it was found that the improvement of productivity of the high stands was larger than that of the low stands. Product yield and SI did not decrease even though FFS increased. Stands started to support the sinter cake load just after the melt near the top of the stands solidified. Shrinkage stopped and gas flow rate increased when the stands started to support the sinter cake load. Porosity above 5mm in sinter cake with stands was larger than that in sinter cake without stands in the lower part of the bed. An increase in the un-sintered portion was not seen near the stands. Sinter products with stands were porous and had good reducibility.

(cf. *ISIJ Int.*, **40** (2000), 1188)

Softening and melting characteristics of self-fluxed pellets with and without the addition of BOF-slag to the pellet bed

G.ZUO

When using 100% self-fluxed pellets in the blast furnace burden, top charged fluxes, especially the BOF-slag, may cause irregularities in operation. The major reason has been theoretically attributed to the problematic slag formation in the furnace. As the melting of pellets is the first step of the slag formation process, the softening and melting properties of LKAB's self-fluxed pellets with and without addition of fluxes are studied experimentally.

The results show that the softening and melting properties of the two types of LKAB's self-fluxed pellets are quite suitable for blast furnace operation. Contrarily, the melting-down characteristics of BOF-slag are variable and harmful to the slag formation under a reducing atmosphere. Adding 5% BOF-slag to the self-fluxed pellets can considerably worsen the softening and melting properties of pellets. It can either increase the softening and melting temperature interval substantially or cause the precipitation of solid phases, mainly di-calcium silicates, in the slag. It is quite likely that the resulting slag will therefore become very viscous, even entirely blocking the melting down of the pellets up to a temperature 1 520°C.

(cf. *ISIJ Int.*, **40** (2000), 1195)

Steelmaking

Modeling of circulating flow in RH degassing vessel water model designed for two- and multi-legs operations

B.LI et al.

A mathematical model has been developed to analyze the circulating flow characteristics in RH Degassing vessel designed for two- and multi- legs system. The homogeneous model with the spatially variable density was used to simulate gas-liquid flow in up-legs. The difference of density between pure liquid and gas–liquid was considered to be a driving force of circulation flow. The volume fraction of gas was obtained by modifying the gas plume model of the stirred ladle. The complicated geometry including ladle, vacuum, up-legs, and down-leg was considered by incorporation of blockage technique. Numerical calculations of the circulating flow have been conducted for the water model of RH degassing vessel with two- and multi-legs with changing the air flowrates from 5 to 35 l/min. Computed velocities at the exit of down-leg agree well with the observed data available in the literature. The momentum transport in RH degassing vessel with multi-legs will be larger than that with two-legs. This is justified based on fact that the velocities in RH degassing vessel with multi- legs tend to be uniform, *i.e.* the mean velocity of bulk in a ladle is remarkably larger than that in two-legs. Simulated transient concentration profile of the tracer from top surface to interior shows clearly the difference of flow characteristics between two- and multi-legs RH degassing vessels.

(cf. *ISIJ Int.*, **40** (2000), 1203)

Casting and Solidification

Texture and deformation behavior through thickness direction in strip-cast 4.5wt% Si steel sheet

J.Y.PARK et al.

Fe–4.5wt%Si strips were made using vertical type twin-roll strip casting process, and the microstructure and texture of as-cast strips were studied through thickness direction. The heterogeneity of the texture and microstructure through thickness direction was observed. Between the subsurface layer and the middle layer, Goss texture, with the subgrains of low angle grain boundary was evolved by the shear deformation. In the center layer, major rolling and recrystallization textures with minor solidification texture were evolved.

The deformation behavior during strip casting process was simulated by hot rolling of Al alloy with temperature gradient through thickness direction. And the shear and normal strains distribution through thickness direction were measured. The heterogeneity of the texture and the microstructure through thickness direction resulted from the strength gradient, which originated from the temperature gradient through thickness direction.

(cf. *ISIJ Int.*, **40** (2000), 1210)

Instrumentation, Control and System Engineering

An adaptive approach to improve the accuracy of a rolling load prediction model for a plate rolling process

S.NISHINO et al.

We present a method that integrates off-line rule identification and an on-line adaptive approach to improve the accuracy of a rolling load prediction model for a plate rolling process. Based on the physical model of a plate rolling process, this work presents an empirical and adaptive approach to improve the accuracy of a rolling load prediction model. Our method consists of an off-line rule identification method and an on-line adaptive method. Using a hierarchical clustering method, our rule identification method finds a set of optimal rules that determine appropriate model parameters depending on an operational environment. In contrast to traditional approaches where such rules are determined in an ad-hoc manner, our method provides a "systematic" method to find optimal rules under the specification on model accuracy. Then, using a recursive least-square error method, our on-line adaptive method tunes model parameters by feeding back the observed model errors. Our off-line approach is effective to deal with nonlinear characteristics of the process, and our adaptive approach guarantees to maximize and to maintain the accuracy even if time passes. A successful application of the proposed ap-

proach to the plate rolling process is also shown.

(cf. *ISIJ Int.*, **40** (2000), 1216)

Forming Processing and Thermomechanical Treatment

Finite element analysis of deep drawing and ironing process in the steel D & I canmaking

J.NAM et al.

The bodymaking of D & I can consists of a deep drawing process, a redrawing process and a multistage wall ironing process. From the viewpoint of mechanics, it can be classified into a complicated high-speed forming process, including nonlinear and coupled thermal-mechanical contact problem. In this study, an axisymmetric non-isothermal finite element analysis using the FEA code ABAQUS has been conducted to analyze the continuous steel D & I canmaking process from deep drawing to three stages of wall ironing. Information on punch load histories, stress/strain distributions and temperature increases are obtained from the analysis. To compare the results from the FE analysis, canmaking experiments utilizing a pilot canmaking line are also carried out. The material considered is a tinplate, a type of low carbon steel for the commercial production of steel D & I can.

(cf. *ISIJ Int.*, **40** (2000), 1223)

Development of a computer code for the interpretation of results of hot plane strain compression tests

B.KOWALSKI et al.

In the present work an investigation of constitutive equations is made to obtain good fit to experimental data and ensure proper extrapolation out of experimental range of plane strain compression tests to low and high values of Zener–Hollomon parameter, which are required in finite element modelling. A computer program for optimisation of rheological parameters of material was developed. Optimisation using experimental data for two ultra low carbon steels was made and the results are compared with measured stress–strain curves. The obtained constitutive equations were used in the finite element model and comparison between experimental and computed displacement–force curves is made. The influence of inhomogeneity of strain rate, strain and temperatures distribution during compression tests on flow curves is illustrated.

(cf. *ISIJ Int.*, **40** (2000), 1230)

Welding and Joining

Effect of Mn and Ni on the variation of the microstructure and mechanical properties of low-carbon weld metal

B.Y.KANG et al.

Low-carbon weld metals with various amounts of Mn and Ni addition were made using metal-cored wires and Ar–2%O_2 shielding gas, and their mechanical properties were evaluated. The objective of the research, aimed to develop welding consumables with better resistance to cold cracking, was to determine the optimum composition ranges of Mn and Ni, in the presence of carbon content less than 0.02%. The hardness of weld metals were found to increase linearly with Mn and Ni, which was attributed mainly to solid solution strengthening and in part to formation of hard phases. Varying Ni content influenced Charpy impact energy, the extent of which depended on Mn content. For a low-Mn composition, Ni addition increased hardness without sacrificing impact toughness whereas for a high Mn composition, Ni deteriorated the impact toughness seriously and caused intergranular fracture. The fracture path followed columnar grain boundaries that are identical to prior austenite grain boundaries since no δ-ferrite phase formed during solidification. Accordingly, these boundaries without having ferrite phase were susceptible to cracking under dynamic loading. Based on hardness and impact resistance, the optimum levels of Mn and Ni were suggested to be 0.5–1% and 4–5%, respectively.

(cf. *ISIJ Int.*, **40** (2000), 1237)

Transformations and Microstructures

Microstructural and mechanical characteristics of low alloyed Ni–Mo–Cu austempered ductile iron

B.BOSNJAK et al.

The present study investigated the effect of austempering temperature and austempering time on the microstructure and mechanical properties of low alloyed Ni–Mo–Cu ductile iron. The effect of austempering parameters and alloying additions on the austemperability of treated ductile iron has been estimated, too.

Specimens were austenitised at 900°C for 120 min, then austempered for 10, 30, 60, 120, 240 and 360 min at 300, 350 and 400°C respectively, and examined by light and scanning electron microscopy. The structure consisted of bainitic ferrite containing retained austenite, the amount of which increased, and the carbon content of which decreased, with increasing austempering temperature. The carbon content of austenite has been evaluated by measuring the lattice parameter by X-ray diffraction.

After short periods of austempering time in iron, the carbon content of the retained austenite decreases and on subsequent cooling to room temperature it transforms to martensite.

The volume fractions of retained austenite, bainitic ferrite, martensite and austenite carbon content was correlated with microstructural changes and mechanical properties. Optimum properties are obtained at intermediate austempering periods (120–240 min) when both the amount of retained austenite and austenite carbon content are maximum.

(cf. *ISIJ Int.*, **40** (2000), 1246)

Effect of Ti addition on the potency of MnS for ferrite nucleation in C–Mn–V steels

J.Y.PARK et al.

The variation of precipitation behavior of MnS has been thermodynamically calculated in V-bearing C–Mn steels by substituting Ti for V. The use of two different set of solubility data for $Ti_4C_2S_2$ and TiS reported in literatures leads to a completely reversed precipitation behavior of MnS. The result of experimental observations is in qualitative agreement with the calculated result using the solubility data of Liu and Jonas. The calculated result showed, contrary to the case of V-containing steel, that the precipitated amount of MnS in steels bearing Ti-only rather decreases with decreasing temperature and that this is due to the formation of $Ti_4C_2S_2$. Controlled cooling experiments with interrupted quenching technique showed that MnS directly acts as the nucleation site for ferrite and that its nucleation potency depends on the precipitation behavior of MnS. Namely, MnS rarely acts as a nucleation site for ferrite in steels where its precipitated amount decreases with decreasing temperature.

(cf. *ISIJ Int.*, **40** (2000), 1253)

Effect of inclusion size on the nucleation of acicular ferrite in welds

T.K.LEE et al.

Low-carbon steel weld with a high density of oxide inclusions prepared using a experimental metal-cored wire has been examined to study the effect of inclusion size on the formation of acicular ferrite, and to understand the role of inclusion in the nucleation of ferrite lath. Depending on the ferrite morphology associated with inclusions, a total of 282 inclusions observed under TEM could be classified into two groups, i.e. the non-nucleant and the nucleant. Experimental results showed that the group of inclusions acted as nucleant were appreciably larger in size compared with those of non-nucleant resulting in the increased probability of nucleation with the increase of inclusion size, even though the chemical and structural natures appeared to be the same. The group of nucleant-inclusion was further divided into two types depending on the degree of nucleation, which was evaluated by the number of ferrite lath nucleated. Statistical analysis performed on inclusion size indicated that the larger the inclusion size is the more ferrite laths could be nucleated. Those laths nucleated from a large single inclusion have grown in many different radial directions and mostly had a different crystallographic orientation from those of adjacent ferrite laths. As a result of this study, it is demonstrated that larger inclusions are indeed more potent nucleation sites when compared with those of smaller size. Thus it could be concluded that the provision of the inclusion surface as for the inert surface for the heterogeneous nucleation of acicular ferrite lath would be the principal role of inclusions playing in the weld metal of low alloy steels. Other possible mechanisms were also considered, but they were unlikely to be operated in the present weld metal system.

(cf. *ISIJ Int.*, **40** (2000), 1260)

Thermodynamics of microstructure control by particle dispersion

T.Nishizawa

Even though microalloying was the most striking advance in the progress of steel technology in the later half of the 20th century, there are still uncer-

tainties as to how each individual microalloying element functions in steel. In the present work, microstructure control by the fine dispersion of TiO and AlN particles has been analyzed from a thermodynamic viewpoint. TiO particles, which act as effective inoculants for the formation of an equiaxed fine grain structure during solidification are categorized as a metallic oxides from the Ti–TiO phase diagram. On the other hand, AlN particles which precipitate anisotropically in the Fe matrix and induce a texture or abnormal grain growth due to their inverse-pinning effect on specified boundaries, are characterized as ionic nitrides. Particle dispersion and the ultra-refinement of grain structure are examined from this viewpoint and a simple model for grain-boundary thickening in Fe alloys due to ultra-refinement is presented.

(cf. *ISIJ Int.*, **40** (2000), 1269)

Mechanical Properties

Effect of rare earth metals on the microstructure and impact toughness of a cast 0.4C–5Cr–1.2Mo–1.0V steel

J.LAN et al.

Die-making technology directly produced by precise casting technology such as investment and ceramic casting method was a promising technology due to its lower manufacture cost and shorter period in comparison with traditional die-making technology. However, the poor mechanical performance of cast materials, especially low impact toughness, was a main obstacle to the application of cast dies and molds.

With a view to improve the impact toughness of CH13 steel (0.4C–5Cr–1.2Mo–1V steel), which was ever used to cast dies for die casting dies, rare earth was added into CH13 steel in our research. It was shown that the dendrite microstructure in CH13 steel had been ameliorated and the segregation ratios of alloying elements were decreased greatly after the addition of rare earth. Grain boundary carbides in MCH13 (CH13+rare earth) steel had also been inhibited. The impact toughness of MCH13 steel had been improved considerably and the fractography of MCH13 displayed more plastic characteristic. Through thermodynamics and two-dimensional lattice disregistry analysis, it was demonstrated that rare earth inclusions in MCH13 steel act as the heterogeneous nuclei, weaken segregation of alloying elements and improve the impact toughness

(cf. *ISIJ Int.*, **40** (2000), 1275)

Foam structure effect on the compression behavior of foamed aluminum alloy

C.C.YANG et al.

The effect of the foam structure on the compression behavior of an A–Si–Mg alloy foam, which was produced by a liquid metal method was experimentally investigated. The compressive stress–strain behavior is discussed due to the deformation of a cell within the foam. It is found that the foam with an 81.3% porosity has both a higher energy absorption capacity and a higher efficiency. The compressive strength decrease as the porosity increases. Experimental result showed that the low compressive strength is attributed to cells imperfection due to the higher porosity.

(cf. *ISIJ Int.*, **40** (2000), 1283)