（＊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

Reduction kinetics of hematite powder mechanically milled with graphite

I.SEKI et al.

Reduction behavior of iron oxides mixed with graphite has been quantitatively investigated using a high temperature X-ray diffractometer. The mixture was mechanically milled using a vibration mill and heated under He gas flow from room temperature to 1 550 K with the heating rate of 10 to 40 K/min. The diffraction pattern showed the sequential change of products by reduction from hematite to iron through magnetite and wustite. The temperature at which each reduced product sequentially appeared was decreased by several ten degrees with increasing mechanical milling time up to 160 min. The intensity change of diffraction profiles of constituents with temperature was in accordance with the chemical stoichiometry of reduction reactions. The reduction reactions were first order of reaction. The activation energy of reaction decreased and the frequency factor of reaction increased with increasing mechanical milling time. On the other hand, the mixture of milled graphite powder and non-milled hematite powder gave less effect to the activation energy and frequency factor than the milled mixture.

(cf. *ISIJ Int.*, **46** (2006), 1)

Reduction of zinc oxide in manganese furnace dust with tar

R.SHEN et al.

Manganese furnace dust is formed when volatiles and fines are cleaned by wet scrubbers from the offgases from manganese alloy smelting furnaces. Impediments to the recycling of the manganese furnace dust back to the ferroalloy furnaces are handling due to the presence of tar, and the potential accumulation of zinc in the furnaces, which can cause irregularities in their operation. This paper examines reduction of zinc oxide from manganese furnace dust formed during ferromanganese and silicomanganese production at Tasmanian Electro Metallurgical Company. Zinc oxide was reduced by tar in the furnace dust above 800°C. The reduction rate increased with increasing temperature with almost complete zinc removal at 1 100°C. The effects of gas atmosphere, pellet size, pressure applied in pellet preparation, as well as mixing of furnace dust with manganese ore, on zinc oxide reduction and removal were studied.

(cf. *ISIJ Int.*, **46** (2006), 8)

Characteristics of particle size distribution of deoxidation products with Mg, Zr, Al, Ca, Si/Mn and Mg/Al in Fe–10mass%Ni alloy

H.OHTA et al.

In the experiments of an Fe–10mass%Ni alloy deoxidized with Mg, Zr, Al, Ca, Mn/Si and Al/Mg at 1 873 K, the characteristics of particle size distributions have been studied as a function of holding time, amount of deoxidant and order of deoxidant addition. The peak height in particle size distribution decreases and the modal value increases with increasing holding time. The width of the distribution curve is larger for Al_2O_3 particles and smaller for liquid $CaO–Al_2O_3$ and $MnO–SiO_2$ particles. The number of particles increases with an increase of deoxidant for a given initial oxygen content and holding time. In the case of Al followed by Mg deoxidation, the particle size distribution is almost the same as that obtained by only Al. The size distribution in case of Mg followed by Al deoxidation is almost the same as that by only Mg.

(cf. *ISIJ Int.*, **46** (2006), 14)

Dispersion behavior of MgO, ZrO_2, Al_2O_3, $CaO–Al_2O_3$ and $MnO–SiO_2$ deoxidation particles during solidification of Fe–10mass%Ni alloy

H.OHTA et al.

The growth mechanism of deoxidation particles during solidification and dispersion behavior in mircosegregation domain have been studied in the experiments where an Fe–10mass%Ni alloy deoxidized with Mg, Zr, Al, Ca or Mn/Si was cooled from 1 873 to 1 673 K at 50 $K \cdot min^{-1}$, followed by rapid quenching. In a plot of the mean particle size versus time elapsed in liquid state and a plot of the number of particles per unit area *versus* time, the particle growth during cooling and subsequent solidification can be explained by Ostwald ripening. The Al_2O_3 particles are pushed to the region of final solidification at lower cooling rate, but the MgO and ZrO_2 particles are engulfed. Engulfment and pushing of particles are discussed based on the wetting/interfacial energy model and the critical velocity of particle engulfment and pushing transition.

(cf. *ISIJ Int.*, **46** (2006), 22)

Liquid immiscibility in Fe–Cu–B system

K.TAGUCHI et al.

The metal in the shredder dust, which is produced from scrapped automobiles and home electric appliances by shredding and sorting, is mainly composed of iron and copper. It is more desirable to reuse it as ferrous and cupreous resources by separating and recovering iron and copper. The Fe–Cu binary system has a single liquid phase in molten state. On the other hand, it is reported that by carbon, phosphorus or silicon addition, two liquid phases separation of iron and copper occurs. In the present work, the two liquid phases separation is studied in the Fe–Cu–B system, and the boron addition is found to be more effective for the phase separation. From the equilibrium relation of the phase separation at 1 873 K, the first-order and the second-order interaction parameters of boron for copper in molten iron have been derived as follows:

$$\epsilon^{B}_{Cu(in\ Fe)} = 0.18(\pm 0.01) \quad ([mass\%B] < 3.3)$$

$$r^{B}_{Cu(in\ Fe)} = -0.015(\pm 0.001)$$

(cf. *ISIJ Int.*, **46** (2006), 29)

Characteristics of particle size distribution in early stage of deoxidation

H.SUITO et al.

The spread of the size distributions obtained by deoxidizing an Fe–10mass%Ni alloy with Zr, Mg, Al, Ca and Si/Mn has been discussed with particular emphasis on the particle size distribution soon after the nucleation of deoxidation product. The geometric standard deviation in size distribution was found to be related to the interfacial energy between oxide and liquid Fe, $\gamma_{oxide-Fe(l)}$. The nucleation rate decreases with an increase in $\gamma_{oxide-Fe(l)}$ based on the homogeneous nucleation theory. Thus, the geometric standard deviation decreases with increasing the nucleation rate in which $\gamma_{oxide-Fe(l)}$ is low such as the case of $MnO–SiO_2$ particles. The experiment in which an Fe–10mass%Ni alloy was first deoxidized with Ti followed by Mg was carried out and narrow size distribution was obtained by separating the nucleation and growth processes.

(cf. *ISIJ Int.*, **46** (2006), 33)

Effects of dissolved oxygen and size distribution on particle coarsening of deoxidation product

H.OHTA et al.

The growth mechanism for deoxidation products of MgO, ZrO_2, Al_2O_3, $CaO–Al_2O_3$ and $MnO–SiO_2$ in an Fe–10mass%Ni alloy has been studied under the condition of no fluid flow by considering the effects of dissolved oxygen and size distribution on Ostwald ripening. The coarsening rate of particles is largely dependent on the dissolved oxygen content. The spread of particle size distribution decreases in the order of $Al_2O_3 > ZrO_2 > MgO > CaO–Al_2O_3 > MnO/SiO_2$ particles and that of solid Al_2O_3, ZrO_2 and MgO particles becomes narrower with holding time. The coarsening rate is also affected by the spread of size distribution curve and this is the reason that the coarsening rate of Al_2O_3 particles is larger than that predicted from dissolved oxygen content.

(cf. *ISIJ Int.*, **46** (2006), 42)

The effect of aluminium content on thermophysical properties of Ni-based superalloys

K.C.MILLS et al.

Ni_3Al is the principal component in the γ' phase formed in Ni-based superalloys but Ni_3Cr and Ni_3Fe can also contribute to the γ' phase at temperatures below 820 K. Approximate values for the γ' phase content can be derived from a relationship based on (mass% Al). In a previous publication it was shown that the density in both the solid and liquid alloys was dependent upon the γ' phase (or Al) contents in the alloy. Consequently, the effect of the γ' phase on other thermophysical properties (C_p, enthalpy, electrical resistivity, thermal conductivity and diffusivity) have been investigated. Linear relations were found between the property values around 300 K and the mass% Al. It was also found that property–temperature relationships were also affected by the γ' phase (or Al) contents. Although it is known that the strong bonding between Ni and Al atoms affects the density of liquid alloys, we were unable to establish any such relationship for the other properties for liquid alloys because of the large experimental uncertainties in the measurements of these properties. This study has revealed that there is an urgent need for accurate values for C_p, electrical resistivity, thermal diffusivity and con-

ductivity for liquid, Ni-based superalloys.

(cf. *ISIJ Int.*, **46** (2006), 50)

Ironmaking

Effect of tuyere blocking on melter gasifier performance

S.PAL et al.

Normally, blast furnace and COREX operate with all tuyeres. However, often, for various reasons it is required to operate the furnace by blocking one or multiple tuyeres. This induces asymmetric transport phenomena at the environs of the blocked tuyere. A 3D mathematical model of the COREX melter gasifier has been developed analyzing this phenomenon. Predicted result shows that even though there exists asymmetry around the blocked tuyere zone, the hot metal temperature is not affected significantly.

(cf. *ISIJ Int.*, **46** (2006), 58)

Proper MgO addition in blast furnace operation

F.SHEN et al.

Based on laboratory experiment, the effects of MgO on sintering process and metallurgical properties of sintered ore are examined. The experiment results show that, adding no or small amount of MgO in sintering, the sintering productivity can be improved, and the sintered ore can have high cold strength and small temperature range of cohesive zone and as a result the permeability of cohesive zone can be improved and the total pressure drop of blast furnace (BF) can be decreased. In this paper a new process of proper MgO addition into BF operation is proposed and in this process MgO content in BF slag can meet the requirement and at the same time RDI of sintered ore is low.

(cf. *ISIJ Int.*, **46** (2006), 65)

Casting and Solidification

Squeezing segregation—investigation with laboratory experiments

K.SCHWERDTFEGER et al.

If a solidifying alloy is deformed the interdendritic liquid and the solid phase of the mushy zone may move relative to each other. Since their compositions differ macrosegregation will result. This phenomenon may occur in twin-roll casting of strip and in thin-slab casting when the thickness of the strip or of the strand, respectively, is reduced above the nip of the rolls or in a tong segment below the mold. Also soft reduction in conventional continuous casting makes concentration changes in the center plane according to the compression mechanism. We call this type of segregation "squeezing segregation" because the residual melt is squeezed out of the dendritic network to other parts of the body. In the present work the mechanism of the squeezing segregation has been investigated experimentally using a laboratory setup with which ingots of iron–carbon alloys were compressed during solidification with a rolling duo installed below the mold. Minima of carbon content down to about 50% of the initial carbon content were observed at the centerplane of the solidified ingot. The effect was also treated theoretically with a simple mathematical model.

(cf. *ISIJ Int.*, **46** (2006), 70)

Squeezing segregation in continuous casting of steel slabs caused by in-line thickness reduction

H.EISERMANN et al.

A mathematical model is presented to predict macrosegregation in steel slabs caused by in-line thickness reduction during solidification. The differential equations for continuity of total mass and for mass of solute elements, for transport of heat and for transport of momentum, together with additional equations describing the local equilibrium between solid and liquid phases in the mushy zone and the deformation behavior of the dendrites have been solved. The result is that in-line thickness reduction can cause macrosegregation involving concentration minima and maxima. The computed flow field in the mushy zone and profiles of carbon and manganese originating in selected situations are given. Experimentally determined concentration profiles are used to confirm the findings of the model.

(cf. *ISIJ Int.*, **46** (2006), 75)

Precipitation behavior of copper, tin and manganese sulfide at high temperature in Fe–10%Cu–0.5%Sn alloys

K.YAMAMOTO et al.

Tramp elements such as Cu or Sn cause a severe hot shortness. Any tramp elements have been rejected and diluted below a certain limit by the use of virgin iron source. On the other hand, the steel properties are improved if Cu precipitates are very fine and uniformly dispersed in steels. Cu is the useful alloying element for increasing hardness and improving of r-value. Recently, it has been found that MnS precipitates have a good positive effect on the heterogeneous precipitation of Cu in grains. In this study a confocal scanning laser microscope with an infrared image furnace was used to carry out the *in-situ* observation of precipitation behavior at high temperature. To estimate the phase diagram, alloys were analyzed by a differential scanning calorimetry (DSC) method. It is clear that the domain of γFe phase becomes smaller and the domain of the liquid phase becomes larger with the addition of Sn. As a result of observation by the confocal laser microscope, the number of precipitates increased at higher temperatures with MnS than without MnS. The observed precipitates are classified into three types. Type "I" is the Cu(Sn) precipitate at the γFe grain boundary. Type "II" is the precipitate found in the γFe grains. One is the Cu(Sn) and another complex precipitate is composed of εCu, (Mn, Cu)S and $Cu_{7.2}S_4$. Type "III" is the smallest εCu precipitate in the αFe grains. They nucleated after γ/α phase transformation and the size is less than 100 nm.

(cf. *ISIJ Int.*, **46** (2006), 82)

Forming Processing and Thermomechanical Treatment

The influence of reheating temperature and direct-cooling rate after forging on microstructure and mechanical properties of V-microalloyed steel 38MnSiVS5

G.DINI et al.

With the aim of replacing quenched and tempered forging parts and reducing by this way costly and time consuming operations; an industrial forging procedure was developed to evaluate the influence of thermomechanical processing parameters on the microstructure and mechanical properties of vanadium microalloyed steel. In order to study the influence of reheating temperature, after determining the dissolving temperature of vanadium carbonitrides precipitates, samples were heating in temperature rang 1 000 to 1 200°C. After austenitization at 1 100°C, the microalloyed steel billets were forged in a hydraulic press and then cooled with different cooling rates. The metallography and mechanical testing results indicated that by increasing the reheating temperature, the strength and toughness of V-microalloyed steel have not change significantly and so the temperature of 1 200°C was selected for forging. By increasing cooling rate, both strength and toughness improve.

(cf. *ISIJ Int.*, **46** (2006), 89)

Mechanism of edge seam defects of stainless steel generated during hot plate rolling

C.G.SUN et al.

A finite element-based, integrated process model is presented for a transient, coupled analysis of the thermal and mechanical behavior of type 304 stainless steel during hot plate rolling process. The validity of the proposed model is examined through comparison with measurements. The model's capability of revealing the effect of diverse process parameters is demonstrated through a series of process simulation. Discussions are made on the effect of various rolling conditions on the generation of edge seam defect.

(cf. *ISIJ Int.*, **46** (2006), 93)

Welding and Joining

Influence of welding speed on microstructure and oxidation behaviour of laser welded austenitic stainless steels

S.K.SAMANTA et al.

Microstructure and high temperature oxidation behaviour of laser weldments of 316L and 316LN steels have been found to influence by the variation in welding speed. Ferrite content and ferrite morphology change for both type 316L and 316LN laser weld with welding speed. Laser weldments consisting mainly of weld metal and base metal region of two austenitic stainless steels (ASS) were oxidized in dry air at 973 K for 240 h. Steel weldment was found to have a higher oxidation rate when joined with lower welding speed of 11.66 mm/s as compared to 25 mm/s speed. On the other hand, 316LN

steel weldments have indicated much superior oxidation resistance property under similar condition. Oxidation behaviour of two ASS weldments has been correlated with microstructure and oxide scales formed over the different regions have been characterized by scanning electron microscopy (SEM/EDXA).

(cf. *ISIJ Int.*, **46** (2006), 100)

Surface treatment and Corrosion

Effect of polyethylene glycol on the morphology of Zn electrodeposited on steel sheet

H.NAKANO et al.

Zn electrodeposition was carried out on a steel sheet galvanostatically at 1 500 A/m^2 in un-agitated sulfate solution of 40°C to investigate the effect of Polyethylene Glycol (PEG) addition on the morphology of Zn. *In situ* observation by atomic force microscopy showed that the growth of deposited Zn proceeded through the advance of macro-steps in platelet crystals to the [21$\bar{3}$0] direction. The addition of PEG to the solution brought about a decrease in size and macro-step height and an increase in inclination of platelet crystals of deposited Zn. In PEG-containing solution, the crystal orientation index of (0002) Zn decreased, while those of (11$\bar{2}$0), (10$\bar{1}$1), (10$\bar{1}$0)Zn correspondingly increased. This change in the crystal orientation generally corresponds to the macro morphology of deposited Zn. The surface roughness of initially deposited Zn was larger in PEG-containing solution than in PEG-free solution due to the decrease in orientation index of (0002)Zn. However, with increased coating weight, the roughness was smaller in PEG-containing solution due to the decrease in size of Zn platelet crystals.

(cf. *ISIJ Int.*, **46** (2006), 106)

Nitriding of interstitial free steel in potassium–Nitrate salt bath

Y.Z.SHEN et al.

A study has been made of nitriding of interstitial free (IF) steel in the potassium–nitrate salt bath at temperatures ranging from 400 to 650°C. The salt is decomposed to generate nitrogen and oxygen. Nitrogen diffuses into steel, or steel is nitrided, while oxygen reacts on steel surface to form the oxide scale. The oxide scale thickness is much smaller than the nitriding thickness. Most of nitrogen resides in steel as a form of interstitial solid-solution. For nitriding at higher temperatures, nitride precipitates (γ'-Fe_4N and ζ-Fe_2N) exist mostly in grain boundaries and partly in grains of the steel. The nitrate nitriding gives rise to much larger nitriding depth than other nitriding methods at similar nitriding temperature and time. The nitrate nitriding of steel substantially increase its tensile strength as well as hardness, *e.g.*, an IF steel specimen nitrided at 650°C for 1.5 h shows a tensile strength of 916 MPa, which is 2.2 times higher than that of non-nitrided IF steel specimen, and an elongation of 20% at 70°C. Severe serrations are observed in flow curves of nitrided steel specimens, mainly due to dynamic strain aging that occurs because of interaction between dissolved nitrogen and moving dislocations. The effective diffusion coefficient of nitrogen D_N obtained from the nitriding data, $D_N=D_0\exp(-Q/RT)$ with $D_0=3.789\times10^{-7}\,m^2\cdot s^{-1}$ and $Q=76.62\,kJ\,mol^{-1}$, is approximately the same as that for diffusion of nitrogen in α-iron.

(cf. *ISIJ Int.*, **46** (2006), 111)

Transformations and Microstructures

Effects of hot deformation and subsequent austempering on the mechanical properties of Si–Mn TRIP steels

Z.LI et al.

In the present paper, effects of hot deformation and subsequent austempering on the mechanical properties of hot rolled Si–Mn TRIP steels were investigated. Thermomechanical controlled processing (TMCP) was conducted by using a laboratory hot rolling mill, in which three different kinds of finish rolling reduction, temperatures and austemperings with various isothermal holding duration were applied. The results have shown that polygonal ferrite, granular bainite and larger amount of stabilized retained austenite can be obtained by controlled rolling processes. Ultimate tensile strength, yield strength and total elongation increase with increasing the amount of deformation and decreasing finish rolling temperature due to the stabilization of retained austenite. Tensile strength and total elongation can reach the maximum values (791 MPa and 36%, respectively), and isothermal holding 20 min at 400°C after hot deformation has been proved to be the optimum treatment.

(cf. *ISIJ Int.*, **46** (2006), 121)

β Grain refinement due to small amounts of Yttrium addition in $\alpha+\beta$ type titanium alloy, SP-700

S.HOTTA et al.

The effect of small amounts of yttrium addition on refinement of β grain size and grain growth behavior in SP-700 alloy with Ti–4.5%Al–3%V–2%Fe–2%Mo was investigated in the temperature region from 1 223 to 1 573 K. Yttrium and oxygen contents in yttrium-added alloys were varied from 0.007 to 0.070% and 0.017 to 0.086%, respectively. Such a small amount of yttrium addition as 0.007% resulted in marked β grain refinement. Variation of β grain size with the heating temperature exhibited rapid grain growth at the particular temperature, which became higher with the increase of yttrium or oxygen content in alloys. It was confirmed that β grain refinement and grain growth behavior with the heating temperature in yttrium-added alloys were brought about by fine precipitates of yttria and dissolution of these precipitates into the β matrix at the higher temperature. TEM and SEM observations of yttrium-added alloys revealed the cubic shape of yttria precipitates with the size of 0.1 to 0.2 μm, and this range of the precipitate's size was well fitted to results analyzed by modified Zener' model for pinning of grain boundary due to a fine particle. Based on assumption that the onset temperature of rapid grain growth corresponds to the re-dissolution temperature of yttria into the β phase, solubility product of Y_2O_3 in reaction of $2Y+3O\leftrightarrows Y_2O_3$ was obtained in use of data of variation of the onset temperature of rapid grain growth with yttrium and oxygen contents in alloys. It was also confirmed that yttria powder could be used as an alloying additive of yttrium in melting of yttrium-added alloys.

(cf. *ISIJ Int.*, **46** (2006), 129)

Tempering kinetics of the martensitic phase in DP steel

T.WATERSCHOOT et al.

The increase in the yield stress of dual phase (DP) steels, resulting from the static strain ageing phenomenon, commonly referred to as bake hardening (BH), gives an important contribution to the additional in-service strength of outer auto body parts, *e.g.* with respect to the dent resistance of the components made with DP steel. In order to understand this large BH effect, the role of the different constituents of the DP steel during this process needs to be considered. The various stages of tempering phenomena taking place in the martensite phase were investigated in detail by means of precision dilatometry and X-Ray Diffraction (XRD). The succession of the various tempering reactions that are characterised by typical volume changes was determined using both constant heating rate and isothermal dilatometric tests. The measurements made it possible to distinguish five distinct stages of structural changes during tempering: (I) the redistribution of carbon atoms, (II) the precipitation of η- or ε-carbide, (III) the formation of Hägg-carbide, (IV) the decomposition of retained austenite, and (V) the transformation of transition carbides to cementite.

(cf. *ISIJ Int.*, **46** (2006), 138)

Development of technique for identification of phase transformation model parameters on the basis of measurement of Dilatometric effect—Direct problem

M.KRZYZANOWSKI et al.

A new thermal-mechanical finite element model capable of taking into account changes in the specific volume during austenite to ferrite γ–α transformation during cooling has been developed. This model, coupled with any of the existing phase transformation models, allows simulation of the sample shortening due to both thermal contraction and the dilatometric effect. The solution is considered as a direct problem model for inverse calculations. The distance between predicted and measured sample elongations is formulated as the cost function for the inverse analysis. It has been shown that the random distribution of the appearing ferritic phase within the sample cross section results in more gentle changes in the sample elongations with time during cooling than that in the case of the conventional approach. This allowed achievement of satisfactory agreement between the experimental and predicted curves in the dilatometric test reflecting both the dilatometric effect and thermal contraction of the specimen during cooling through austenite–ferrite transformation temperatures.

(cf. *ISIJ Int.*, **46** (2006), 147)

Transmission electron microscopy observations of the phase separation of $D0_3$ precipitates in an elastically constrained Fe–Si–V alloy

M.Doi et al.

When Fe–16.2mol%Si–13.3mol%V alloy is homogenized at 1473 K for 7.2×10^3 s and then quenched into iced brine, $D0_3$ (ordered bcc) particles appear in the A2 (disordered bcc) matrix. The $D0_3$ particles are cuboidal because of the influence of elastic energy which arises from the lattice mismatch between the A2 matrix and the $D0_3$ particle. When the two-phase microstructure of A2+$D0_3$ is aged at 923 K, the phase separation of $D0_3$ precipitate takes place and fine A2 particles appear in each cuboidal $D0_3$ particle. In the course of further ageing at 923 K, the A2 particles coarsen to become plates in the $D0_3$ particles as a result of elastic energies, then the A2 plates elongate along {100} to reach the A2 matrix surrounding the $D0_3$ particles, and finally the split of $D0_3$ particles is realized. Such a split phenomenon takes place throughout the microstructure to bring the refinement or at least the decelerated coarsening of two-phase microstructure, which is a result of not only the elastic energies but also the chemical free energy.

(cf. *ISIJ Int.*, **46** (2006), 155)

Microstructure evolution in a low carbon Nb–Ti microalloyed steel

K.M.Wu et al.

The micro mechanical properties, stability and three-dimensional (3D) morphology of intragranular ferrite was studied in a low carbon microalloyed steel utilizing nano indentation, three-dimensional reconstruction techniques along with LEO1450 scanning electronic microscopy. The mixed microstructures of intragranular ferrite, granular bainite and lath or plate-like bainite was obtained in a Nb–Ti microalloyed steel, which was water cooled immediately after relaxation for a fixed time as hot deformation ended. The elastic modulus and hardness increased in the sequence of intragranular ferrite, granular bainite and lath or plate-like bainite by approximately 15 GPa and 0.6 GPa, respectively. On the contrary, the tempering treatment of the specimens showed that the stability of the mixed microstructures decreased in the sequence of intragranular ferrite, granular bainite and lath or plate-like bainite. The results of stability, elastic modulus and hardness indicated that intragranular ferrite was formed prior to bainite transformation. The intragranular ferrite thus effectively sectioned the prior austenite into many small zones and thus the bainite transformed at lower temperatures was restricted in the small zones. It is likely that the formation of lath or plate-like intragranular ferrite prior to bainite transformation played an important role in the refinement of mixed microstructures.

(cf. *ISIJ Int.*, **46** (2006), 161)

Mechanical Properties

Flow stress constitutive model of ultra low carbon steel in warm deformation

G.Xu et al.

Warm rolling technique of ultra low carbon steels is a new technology for metal forming. In order to study the flow stress of ultra low carbon steels in warm deformation, experiments of warm deformation of this grade were carried out on a hot simulation machine with the deformation temperature of 750 to 950°C, and strain rate of 1 to 70 s^{-1}. The experimental results have shown that the variation of flow stress with temperature in warm deformation is different from that in austenite deformation under high temperature, although the influences of strain rate and strain on flow stress in warm deformation of ULC steels are similar to those in austenite high temperature forming. A new flow stress constitutive model suitable to ferrite deformation of ultra low carbon steel is deduced in the paper on the basis of theoretical analysis and an actual flow stress model for ULC steels is obtained on the basis of experimental results. The comparisons between prediction values of new model and test values have proven that the new flow stress constitutive models given in the paper have higher precision when they are used to describe the flow stress variations of ULC in warm deformation.

(cf. *ISIJ Int.*, **46** (2006), 166)