（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Effect of magnetic field on γ–α transformation temperature in Fe–Co alloys

T.FUKUDA et al.

Effect of magnetic field on γ (austenite)↔α (ferrite) transformation temperatures in Fe–xCo alloys with x=10, 20, 30 at% has been studied. Following results are obtained: (i) both the $\gamma\rightarrow\alpha$ and $\alpha\rightarrow\gamma$ transformation start temperatures increase with increasing magnetic field; (ii) the equilibrium temperature T_0, which is estimated as the average of the $\gamma\rightarrow\alpha$ and $\alpha\rightarrow\gamma$ transformation temperatures, is almost proportional to magnetic field for the Fe–20Co and Fe–30Co alloys, while it is almost proportional to square of magnetic field for the Fe–10Co alloy; (iii) T_0 increases by about 18 K for Fe–10Co alloy, 24 K for Fe–20Co alloy and 20 K for Fe–30Co alloy when a magnetic field of 10 T is applied. The results are discussed on the basis of the Clausius–Clapeyron equation.

(cf. *ISIJ Int.*, **46** (2006), 1267)

Ferrite transformation in high magnetic field monitored by *in-situ* magnetic measurements

S.RIVOIRARD et al.

For the first time, *in-situ* high temperature magnetic measurements are used to monitor the solid state transformations in steels. The magnetization provides information about the kinetic of the austenite to ferrite transformation, although care must be taken in the experimental procedure and in the data analysis. The isothermal transformation of ferrite following two regimes under magnetic field is confirmed together with the effect of the magnetic field on the nucleation of this phase.

(cf. *ISIJ Int.*, **46** (2006), 1274)

Phase-field modeling of structural elongation and alignment of (α+γ) microstructure in Fe–0.4C alloy during thermomagnetic treatment

T.KOYAMA et al.

During last decade, the phase-field method has emerged across many fields in materials science as the powerful tool to simulate and predict the complex microstructure developments. In this study, the microstructure changes of γ precipitation in polycrystalline α phase during thermomagnetic treatment in Fe–0.4C alloy are modeled using the phase-field method. Using phase-field simulation, the model reasonably represents microstructure changes in Fe–0.4C system quantitatively. In particular, it is shown that the structural elongation and alignment of the (α+γ) two-phase microstructure is influenced by the anisotropic carbon diffusion induced by the magnetic energy at the initial stage of the γ phase formation. Modeling of microstructure developments with the framework of the phase-field method is shown to be a very effective strategy to predict and analyze complex microstructure formation.

(cf. *ISIJ Int.*, **46** (2006), 1277)

Phase transformation and magnetic properties in $Ni_{52}Fe_xMn_{21-x}Ga_{27}$ alloys

K.TSUCHIYA et al.

Effect of chemical composition was investigated on martensitic transformation temperatures, Curie temperature, magnetization for $Ni_{52}Fe_xMn_{21-x}Ga_{27}$ alloys. X-ray diffraction patterns revealed that all the samples were in a single Heusler ($L2_1$) phase state at room temperature. Forward and reverse martensitic transformation temperature, M* and A*, decreased with Fe content, x, up to 15 mol% and then turned to increase by further addition of Fe. Composition dependence of the Curie temperature exhibited a reversed tendency compared with M*. The structure of martensite was 10M for the alloys with x<15 and a mixture of 14M and 10M for x=20. Electron diffraction patterns of $L2_1$ phase exhibited intense diffuse streaks on cooling, which were longer than those observed in ternary Ni–Mn–Ga.

(cf. *ISIJ Int.*, **46** (2006), 1283)

Effects of aging and Co addition on martensitic and magnetic transitions in Ni–Al–Fe β-based shape memory alloys

K.OIKAWA et al.

Effects of low temperature aging and the addition of Co on the martensitic and magnetic transitions in the Ni–Al–Fe β (B2-type structure) alloy system were investigated using differential scanning calorimetry, transmission electron microscopy and vibrating sample magnetometry. The martensitic transition temperatures of a $Ni_{57}Al_{25}Fe_{18}$ specimen homogenized at 1 473 K for 1 h were decreased by aging after homogenization, the maximum decrease by aging being observed at 573 K. On the other hand, the substitution of Co or Fe for Ni induced a decrease of the martensitic transition temperatures and an increase of the Curie temperature, while the substitution of Co for Fe resulted in an increase of the martensitic transition and Curie temperatures. Co was thus shown to be an effective element by which both the martensitic and magnetic transition temperatures can be controlled.

(cf. *ISIJ Int.*, **46** (2006), 1287)

Effect of magnetic field on weld zone by spot-welding in stainless steel

Y.WATANABE et al.

Spot welding is performed through a resistance welding process in which the components to be welded are clamped between two electrodes supplying heat current. It is known that a weld fusion zone and a heat-affected zone (HAZ), which experience high temperature followed by rapid cooling to room temperature, exhibit very different microstructures, compared with those of base materials. The microstructure of the weld fusion zone and HAZ (weld zone) is influenced by many factors such as chemical composition, welding condition and peak temperature. In this study, the effect of magnetic field on HAZ in spot welded stainless steel was studied. For this purpose, deformed and undeformed 301 type stainless steel (Fe–17mass%Cr–7mass%Ni–0.1mass%C–0.5mass%Si–0.99mass%Mn) samples with α' martensite phase and γ austenite phase, respectively, were spot-welded under a magnetic field up to 2 T. The welded surfaces and the cross-section planes were examined using an optical microscope. It was found that the area of HAZ was increased with increasing magnetic field, as well as the heat input power. Moreover, the area of weld zone in deformed stainless steel is larger than that in undeformed stainless steel. Based on the experimental results, the effect of magnetic field on HAZ in spot-welded stainless steel was discussed.

(cf. *ISIJ Int.*, **46** (2006), 1292)

Ironmaking

Model for economic optimization of iron production in the blast furnace

F.PETTERSSON et al.

A method for economic optimization of ironmaking in the blast furnace has been developed. Values for some of the most central operational variables of the furnace were generated by a factorial plan, and were used as inputs to a first-principles model that estimated important performance variables of the process. On the basis of these data a linear process model was developed and subsequently used for minimizing the hot metal production costs. The optimization task was formulated as a mixed integer linear programming problem and was solved by a spreadsheet program. The performance of the model is illustrated by examples, where the specific hot metal production cost is minimized under realistic process constraints. The sensitivity of the model to changes in the constraints or in the price structure is also demonstrated.

(cf. *ISIJ Int.*, **46** (2006), 1297)

Steelmaking

Effect of Cu, Sn and W on the rate of nitrogen dissociation on the surface of molten iron

H.ONO-NAKAZATO et al.

The effects of Cu, Sn, W on the rate of nitrogen dissociation on the surface of molten iron have been investigated at 1 973 K by an isotope exchange method. The rate constant of nitrogen dissociation increases with increasing the content of W. On the other hand, the rate constant decreases with increasing the Cu and Sn contents. These effects of the alloying elements on the rate of nitrogen dissociation depend on the affinity of the solute element with nitrogen in molten iron. The elements with stronger affinity with nitrogen than iron have a stronger effect of enhancing the nitrogen dissociation rate and those with stronger repulsive force against nitrogen have a stronger effect of retarding the nitrogen dissociation. The effect of the alloying elements on the rate of nitrogen dissociation is investigated based on a model proposed from the analysis on the basis of surface concentration of the solute. This model can reasonably represent the variation of the rate constant of nitrogen dissociation with the W content.

(cf. *ISIJ Int.*, **46** (2006), 1306)

Effect of high-temperature field on supersonic oxygen jet behavior

I.SUMI et al.

In the steelmaking process, the behavior of the top blown oxygen jet is an important factor for controlling BOF or EAF operation. Because the temperature in the BOF is very high, jet behavior is still not fully understood. In this study, supersonic oxygen jet behavior in a high-temperature field was investigated by measuring the velocity and temperature of the oxygen jet in a heated furnace, and the results were compared with a jet model proposed by previous researchers. The results showed that velocity attenuation of the jet was restrained and the potential core length was extended in a high-temperature field. Under these experimental conditions, the results were in good agreement with the jet model using Pr=0.715 and Sc=0.708 proposed by Kleinstein. Supersonic jet behavior for SCOPE-JET nozzle, which can be applied in EAF operation to obtain high-energy efficiency, was also investigated. SCOPE-JET had a long potential core and attenuation of the jet in the axial direction was extremely restrained. It was shown to be possible to obtain the jet behavior of SCOPE-JET nozzle using the jet model with the adiabatic flame temperature as the ambient temperature and appropriate temperature attenuation behavior in the axial direction.

(cf. *ISIJ Int.*, **46** (2006), 1312)

Chemical and Physical Analysis

Determination of trace boron in iron and steel by adsorptive stripping voltammetry using beryllon III

T.TANAKA et al.

Adsorptive stripping voltammetry is proposed for determination of boron at low $\mu g\ g^{-1}$ level in iron and steel. Beryllon III was used as a complexing agent for boron(III). Optimum conditions for the formation of the boron(III)–Beryllon III complex were as follows: 0.06 M nitrate–0.04 M sulfate supporting electrolyte at pH 4.5; 1.0×10^{-5} M Beryllon III; 24 h complexation time. The complex was accumulated on a hanging mercury drop electrode at −0.35 V *vs.* SCE for 60 s under stirring, and was subsequently cathodically stripped to −0.8 V *vs.* SCE at a scan rate of $10\ mV\ s^{-1}$ using a differential pulse mode. Interference by iron(III) was eliminated by the complexation with metaphosphoric acid. After cathodic stripping, a single well-defined peak was observed at around −0.5 V *vs.* SCE. The influence of foreign elements on the determination was also evaluated. The calibration graph (peak height *vs.* boron(III) concentration) in the presence of $1\ mg\ mL^{-1}$ iron(III) was linear over a concentration range of $1–25\ ng\ mL^{-1}$ (correlation coefficient >0.999), with a relative standard deviation (n=4) of 2.6% at $10\ ng\ mL^{-1}$. The minimum limit of determination was $1\ \mu g\ g^{-1}$ of boron in iron and steel. The proposed method has been proved to be applicable to the determination of trace boron in iron and steel with good precision and accuracy.

(cf. *ISIJ Int.*, **46** (2006), 1318)

Forming Processing and Thermomechanical Treatment

Springback-free isothermal forming of high-strength steel sheets and aluminum alloy sheets under warm and hot forming conditions

J.YANAGIMOTO et al.

Quasi-isothermal sheet forming experiments of 300 mm square–1 mm thickness sheets are conducted using newly developed forming dies with a built-in heater and a 3 000 kN hydraulic press, and the characteristics of springback reduction due to the elevation in forming temperature are clarified. The springback-free forming of high-strength steel sheets is realized in the warm forming temperature range. This result is confirmed by isothermal V-bending tests in a hot compression testing machine, where a marked decrease in springback is observed when the forming temperature of mild, precipitation-hardened, TRIP and dual-phase steels is higher than 750 K, which is approximately the critical temperature for the onset of ferrite recrystallization.

(cf. *ISIJ Int.*, **46** (2006), 1324)

Surface hardening treatment for C.P. titanium and titanium alloys in use of Ar–5%CO gas

Y.Z.KIM et al.

Surface hardening of C.P. (commercially pure) titanium and titanium alloys in use of Ar–5%CO gas was investigated in the temperature range between 973 K and 1 123 K. Titanium materials used were $\alpha+\beta$ type alloy of Ti–4.5%Al–3%V–2%Mo–2%Fe (SP-700) and β type alloy of Ti–15%V–3%Cr–3%Sn–3%Al (Ti-15-333). Oxidation accompanied with surface hardening in use of Ar–5%CO gas is much reduced compared with that of Ar–20%CO_2 gas. Surface hardening was evaluated by both of the maximum surface hardness and hardening layer depth obtained from hardness distribution profiles in the subsurface region. The former is the highest in C.P. titanium and the lowest in Ti-15-333 alloy, and the latter is the deepest in Ti-15-333 alloy and the shallowest in C.P. titanium. Surface hardening in C.P. titanium is caused by solid solution hardening of oxygen and carbon enriched in the subsurface region. Enrichment of these interstitials in the subsurface region of SP-700 or Ti-15-333 alloys causes the increase of α volume fraction in $\alpha+\beta$ two phases or phase transformation from β to $\alpha+\beta$ two phases, respectively, and surface hardening is primarily controlled by volume fraction of α phase hardened by interstitials enrichment. The other β type titanium alloy of Ti–15%Mo–5%Zr–3%Al yields much marked surface hardening over Ti-15-333 alloy. All of these results were analyzed and discussed based on oxygen and carbon concentration profiles, which were obtained by EPMA, and were also calculated by uni-dimensional diffusion model.

(cf. *ISIJ Int.*, **46** (2006), 1329)

Surface Treatment and Corrosion

Assessment of the Zn/Al metal spraying technology without blast treatment

K.SONOYA

Recently, in the view of maintenance-free type corrosion prevension of steel bridges, thermal spraying with good durability and long life is desired. Zn/Al metal spraying is spotlighted due to its low life cycle cost (LCC). Zn/Al metal spraying without blast treatment, one of corrosion prevension methods, has better efficiency and environmental property, such as less fume, than the conventional method based on JIS H 8305. In this paper a comparison was made on the properties of the Zn/Al sprayed coating without blast treatment and the coating of the conventional method. In the results, it was shown that the coating of Zn/Al metal spraying without blast treatment had the same properties as conventional method based on JIS H 8305.

(cf. *ISIJ Int.*, **46** (2006), 1339)

Transformations and Microstructures

Microstructure and precipitation behavior of Nb, Ti complex microalloyed steel produced by compact strip processing

R.WANG et al.

A comprehensive microstructure analyses were conducted for CSP processed Nb, Ti microalloyed steel, especially focusing on the precipitation behavior of the microalloying elements Nb and Ti. After coiling, the steel exhibits mainly a ferrite microstructure. The average ferrite grain size is 5.3 μm. The ferrite has a transitional morphology from polygonal ferrite to non-polygonal ferrite and is characterized by a moderate dislocation density of $2.47E+10/cm^2$. A high density of Nb, Ti complex star-like or cruciform shaped precipitates exist in the steel. They are Nb-rich and the average size is around 150 nm. About 49% Nb of the total in the steel is tied up in star-like precipitates, thus remarkably reducing the amount of Nb available for austenite conditioning, transformation temperature control and precipitation as small strengthening particles in ferrite. The main strengthening mechanisms found in the steel are the grain refinement and dislocation strengthening. Of the total yield strength, they represent contributions of 44% and 24%, respectively. There is a very little precipitation strengthening in the steel. It is thought that Nb, Ti complex star-like precipitate is prone to form in Ti-containing niobium microalloyed steel produced by compact strip processing.

(cf. *ISIJ Int.*, **46** (2006), 1345)

Continuous cooling transformation temperature and microstructures of microalloyed hypereutectoid steels

A.M.ELWAZRI et al.

The transformation behavior under continuous cooling conditions was investigated for four hypereutectoid steels of 1% carbon with different microalloying additions of vanadium and silicon. Con-

tinuous cooling compression testing of the hypereutectoid steels was employed to study the influence of processing conditions (re-heat temperature), microstructure (prior-austenite grain size) and chemical composition (vanadium and silicon) on the critical transformation temperature (A_{r3}). Overall, for the hypereutectoid steel compositions examined, the transformation temperatures were determined to be relatively stable, with a variation of roughly 15°C when the reheat temperature was changed from 1 000 to 1 200°C. The addition of microalloying elements such as vanadium and silicon was determined to increase the austenite-to-pearlite transformation start temperature of the hypereutectoid steels by about 10–30°C. These changes in the transformation behavior observed with decreasing re-heating temperature and microalloying additions were related to microstructural changes in the hypereutectoid steels, such as prior-austenite grain size refinement, carbide precipitation and grain boundary cementite fragmentation.

(cf. *ISIJ Int.*, **46** (2006), 1354)

Development of ultrahigh strength steel by electroslag refining: Effect of inoculation of titanium on the microstructures and mechanical properties

S.K.MAITY et al.

A low alloy steel with the nominal chemical composition of C 0.3%, Mn 1%, Cr 4%, Mo 1%, V 0.4% with lower amount of P and S is prepared by electroslag refining (ESR). The result of the mechanical properties of this steel after tempering confirms that this steel may be placed in the family of ultrahigh strength steel. The tensile, yield and impact strength of this steel are 1 650 MPa, 1 450 MPa and 300 kJ/m^2 respectively, coupled with good ductility and hardness. Three more steels are prepared by inoculation of titanium during the ESR process similar to above composition. The analysis values of titanium in these steels are 0.07%, 0.20% and 0.4%. The addition of titanium resulted a sharp change in both microstructures and mechanical properties. It is noticed that 0.07% titanium results a sharp increase of tensile properties compared to uninoculated steel. The tensile and yield strength of the 0.07% titanium steel are 1 730 MPa and 1 512 MPa, respectively. Further increase of titanium to 0.2% and 0.4% result a significant drop of mechanical properties compared to steel with no titanium. The optical, SEM, TEM and TEM-carbon replica studies confirms that at lower concentration of titanium (0.07%), finer Ti(C, N) particles are precipitated which are able to restrict the austenite grain sizes. The refinement of austenite grains and consequent finer lath martensite may be the possible reason for strenghthening. Higher titanium (≥0.2%) led to larger carbonitride particles which has no role on grain refinement.

(cf. *ISIJ Int.*, **46** (2006), 1361)

Phase transformation in $Fe_{81.0}Zr_{9.0}B_{10.0}$ metallic glass during thermal annealing and electron irradiation

T.NAGASE et al.

Solid-state phase transitions in $Fe_{81}Zr_9B_{10}$ alloy were investigated focusing on crystallization and amorphization introduced by thermal process and mechanical process of electron irradiation. Melt-spun amorphous phase can not maintain their original structure under thermal heated state at 828 K and electron irradiation at 103 and 298 K, crystallization of this phase occurred. There was a great difference in crystallization behavior between thermal annealing and electron irradiation. Metastable α-Mn type crystalline phase precipitated through thermal crystallization, while nano-crystalline b.c.c. solid solution was formed through electron irradiation induced crystallization. The α-Mn type crystalline phase underwent solid-state amorphization by electron irradiation at 103 and 298 K. Both amorphization and crystallization were observed in $Fe_{81}Zr_9B_{10}$ alloy under electron irradiation in spite of same irradiation conditions, resulting in the occurrence of crystal-to-amorphous-to-crystal (C–A–C) transition.

(cf. *ISIJ Int.*, **46** (2006), 1371)

Modeling thermal desorption analysis of hydrogen in steel

M.ENOMOTO et al.

A computer model was developed to simulate the thermal desorption flux of hydrogen from steel specimens by Dufort–Frankel finite difference method, an explicit scheme which is convergent and stable for all time increment. The influences of experimental parameters, *e.g.* ramp rate, specimen size and duration of exposure at ambient temperature *etc.*, on the desorption spectrum, concentration profile of hydrogen in the lattice and fractional occupancy at the trapping sites, were studied assuming that the major trapping sites were dislocations. The increase in ramp rate caused a marked shift in the desorption peak to a higher temperature, whilst the increase in the specimen size shifted the peak to higher temperatures to a moderate extent. The duration of exposure may have a considerable influence on the thermal desorption spectra when the desorption peak is associated with a lower binding energy trap site.

(cf. *ISIJ Int.*, **46** (2006), 1381)