（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Steelmaking

State of the art in evaluation and control of steel cleanliness (Review)

L.ZHANG et al.

This paper first reviews the current "state-of-the-art" in the evaluation of steel cleanliness, discussing over 20 different methods. The demand for cleaner steels requires lowering non-metallic oxide inclusions and also controlling their morphology, composition and size distribution. Because no single method can measure all of these aspects accurately, it is best to combine several methods together to quantify steel cleanliness in a given operation. Owing to the cost, time requirements, and sampling difficulties, steel cleanliness is widely inferred using total oxygen, nitrogen pick-up, and other indirect methods. Recent cleanliness values using these indicators are summarized for LCAK at many steel plants around the world. Secondly, this paper reviews operating practices to improve steel cleanliness at the ladle, tundish and continuous caster, emphasizing findings quantified with plant measurements. Inclusions come from many sources, including deoxidation, reoxidation, slag entrapment, refractory wear, and chemical reactions. They generate many defects such as cracks and slivers in the steel product. Steel cleanliness is controlled by attention to a wide range of important operating conditions throughout the steelmaking and casting processes. For ladle operations, FeO and MnO in the slag, ladle treatments, and inclusion modification are discussed. For tundish operations, tundish depth and capacity, casting transitions, refractory lining, tundish flux; gas stirring, and flow controls are discussed. Important transfer operations from ladle to tundish and from tundish to mold, such as argon protection, sealing issues, and SEN clogging are summarized. Caster operations reviewed include the effect of casting speed, fluid flow pattern control, surface level control, and caster curvature.

(cf. *ISIJ Int.*, **43** (2003), 271)

Fundamentals of High Temperature Processes

Mechanisms of iron entrainment into slag due to rising gas bubbles

Z.HAN et al.

Iron droplets can be entrained into the slag phase when gas bubbles pass through the molten iron/slag interface. The physical phenomena occurring during passage of single bubbles through the interface were investigated by using *in-situ* X-ray transmission techniques and optical microscopy of the cooled specimens afterwards. Based on the X-ray observations, two mechanisms of entrainment of iron droplets into slag were proposed: large droplets are entrained by jet formation, fine droplets by the rupture of the metal film covering the gas bubble releasing from the iron/slag interface, respectively. The results provide novel erudition of the interaction between the ascending gas bubbles and the slag/iron systems.

(cf. *ISIJ Int.*, **43** (2003), 292)

Effect of surface concentration of alloying elements on nitrogen dissolution rate in molten iron alloys

H.ONO-NAKAZATO et al.

The effects of alloying elements, such as Mn, Cu and Mo, on the rate of nitrogen dissolution in the molten iron alloys are investigated by an isotope exchange technique at 1 973 K. The rate constant of nitrogen dissolution increases with increasing the content of Mn or Mo, which has stronger affinity with nitrogen than iron. On the other hand, the rate constant decreases with increasing the Cu content, which has a repulsive force against nitrogen in iron. The mole fractions of the alloying elements in the surface phase are estimated, and the reaction mechanism is discussed by investigating the dependence of the rate constant on the mole fraction in the surface phase. The effect of alloying elements on the nitrogen dissolution rate depends on the affinity of the solute element with nitrogen in molten iron and the mole fraction in the surface phase.

(cf. *ISIJ Int.*, **43** (2003), 298)

Ironmaking

Melt down behaviour of a fused layer in the blast furnace cohesive zone

S.J.CHEW et al.

The cohesive, or softening-melting zone plays a critical role in determining blast furnace performance and stability. The effect of changes in the permeability of softening-melting ore and the subsequent distribution of gases and liquids around the anisotropic packing structure of coke and ore layers in this region must be understood before the blast furnace can be adequately modelled. This study aimed to address issues related to cohesive zone formation through low-temperature experimentation. Two investigations of meltdown behaviour were performed, classified according to geometrical characteristics. The first 'flat layer meltdown' investigation examined the softening-melting of flat cohesive layers extending across the furnace diameter. This configuration matched that used in high-temperature softening-melting tests. The second 'single layer meltdown' investigation concentrated on a single cohesive layer embedded in a permeable packing. This configuration can be likened to a single cohesive layer in a permeable cohesive zone, where gas is able to bypass ore through intermediate coke slits as permeability is lost. The meltdown of flat cohesive zones was characterised by variability and gas channelling, promoting furnace instability and preventing accurate modelling. The meltdown of single layers demonstrated the possibility of structural variation between the surface and core, and the change in contribution of convection and conduction to heating.

(cf. *ISIJ Int.*, **43** (2003), 304)

Effects of SiO_2 and Al_2O_3 on the lattice parameter and CO gas reduction of CaO-containing dense wustite

T.INAMI et al.

The effects of SiO_2 and Al_2O_3 on the lattice parameter and the initial reduction rate of CaO-containing wustite were studied at 1 273 K. Wustite plates containing 0.5–2 mass% CaO, 0.2–2 mass% SiO_2 and 1 mass% Al_2O_3 were prepared at the mass fractions of $CaO/SiO_2=0.5$–5. The lattice parameter of CaO–SiO_2–containing wustite decreased with decreasing CaO/SiO_2 ratio at a constant CaO content. This corresponded to a decrease of the dissolved content of CaO in the wustite due to a formation of CaO–FeO–SiO_2 compounds. Similarly, the dissolved content of CaO decreased in CaO–SiO_2–Al_2O_3–containing wustite. The process of CO gas reduction within the wustite phase field was traced with the lattice parameter measurement of the partially reduced samples and was analyzed with a mixed-control model of chemical reaction at the surface and the solid state diffusion in the wustite. The chemical reaction rate constant, k', decreased with increasing the amount of SiO_2 addition at a constant CaO content. The dependence of k' on SiO_2 (and Al_2O_3) addition was in good accordance with the change in the dissolved content of CaO in the wustite owing to the formation of the compounds containing CaO. The inter-diffusion coefficient, D, tended to decrease slightly with increasing the amount of compound.

(cf. *ISIJ Int.*, **43** (2003), 314)

Investigation of blast-furnace hearth sidewall erosion by core sample analysis and consideration of campaign operation

A.SHINOTAKE et al.

The sidewall core boring of the Tobata No. 1 BF, which had been blown out in 1998, was carried out. Bricks and residue in the hearth were sampled and investigated in order to estimate the erosion and protection mechanism of the hearth sidewall.

Sampled carbon bricks were observed. [1] A metal-rich layer, [2] a layer which a large amount of metal penetrated, [3] a solid layer which a small amount of metal penetrated, and [4] a weakened layer in which the block has become brittle although metal did not penetrate, [5] a sound layer were observed in this order from the furnace inside side. Na and K are widely distributed from the hot face side to the cold face side, while zinc is accumulated in a high concentration in the brittle layer.

As a result of investigation of the residue in the hearth near sidewall bricks, it became apparent that the residue in the hearth is a layer mainly composed of iron with high carbon concentration. It was estimated that the solidification structure is molten iron which solidified gradually while entraining carbon sources. TiN was observed in some samples by microscopic observation.

From the consideration of period and spatial distribution of temperature rise, it was estimated that flows of molten iron which move in the hearth toward tapholes are the cause of the sidewall temperature rise. The mechanism of sidewall erosion by the shrinkage of the viscous layer and solidified layer near bricks was estimated.

(cf. *ISIJ Int.*, **43** (2003), 321)

Oxidation behavior and caking property of coal under the atmosphere at low oxygen concentration

H.OTA et al.

Eight coals ranging from bituminous coal to brown coal were oxidized in a thermo-balance or a fixed bed reactor using 5 vol% of oxygen at 100–380°C for 10–400 min. The effects of coal particle size, coal rank, oxidation temperature and oxygen concentration on the oxidation behavior of coal were investigated. The caking property, FT-IR spectrum and pyrolysis behavior of sample oxidized were measured. The oxidation behavior strongly depended on the coal rank. The oxidation reaction of highly caking coal was controlled by the rate of internal gaseous diffusion. The caking property of bituminous coal decreases by the oxidation in the oxidative atmosphere of low oxygen concentration of 5 vol%, which corresponds to that in a flue gas.

The aliphatic C–H groups in highly caking coals are easily oxidized during oxidation and remained in coal structure as relatively stable forms. The differences in chemical structure and caking property between the exterior part and the central part of oxidized coal particle was investigated. In the case of highly caking coal, the chemical structure and some properties of oxidized coal depends on the position of the coal particle because the mild oxidation reaction of coal proceeds from the exterior part of coal particle.

(cf. *ISIJ Int.*, **43** (2003), 331)

Prediction model of coke strength after gasification reaction

H.YAMAOKA et al.

Mechanisms of the breakage and fines generation of cokes after gasification reaction were studied standing on the basic viewpoints as follows:

1) The coke is a compound of plural kinds of coke textures with respective strength and reactivity and both the strength and reactivity of coke in total are dominated by the coke textures composition and pore volume fraction.

2) The change in the strength after gasification reaction is caused by the change in the coke textures composition and pore volume fraction due to the gasification reaction.

According to the basic viewpoints, a mathematical model was developed which calculates the change in the coke textures composition and pore volume fraction during gasification reaction and predicts the strength of coke after gasification reaction.

Experiments were made on the gasification and size degradation of cokes using five kinds of coke samples with different coke textures composition and the model was confirmed useful to predict the reaction rates and the strengths after gasification reaction.

(cf. *ISIJ Int.*, **43** (2003), 338)

Casting and Solidification

Influence of phosphorus on solidification structure in continuously cast 0.1 mass% carbon steel

N.YOSHIDA et al.

In 0.1 mass% carbon steels with phosphorus contents ranging from 0.01 to 0.2 mass%, slabs were continuously cast to a thickness of 100 mm with a laboratory scale caster. Their macro- and microstructures were characterized, focusing on the effects of phosphorus addition on the structural evolution during solidification and subsequent cooling. Cast slabs of high phosphorus steels have a fine columnar-γ-grain structure. The mean width of the columnar grain was approximately half of that in the cast slabs without the phosphorus addition. Dispersed globular α grains were observed in the α grain structure of high phosphorus steels. The globular grains evolved at the phosphorus-rich spots in the prior-γ grain. The micro-segregation of phosphorus results in these structural evolutions. Since the phosphorus enrichment stabilizes bcc (δ or α) phase locally at the inter-dendritic region, the phosphorus-rich spot makes δ phase retained to lower temperature for the δ/γ transformation, and provides a predominant site for the γ/α transformation. In the high phosphorus casts, therefore, the dispersed δ phase are thought to pin the γ grain growth more effectively in the $\delta+\gamma$ region when the completion of the δ/γ transformation is remarkably suppressed by the phosphorus segregation.

(cf. *ISIJ Int.*, **43** (2003), 348)

Instrumentation, Control and System Engineering

Adaptive and robust control method with estimation of rolling characteristics for looper angle control at hot strip mill

H.ASADA et al.

In this paper, an adaptive robust control method for looper height control of hot strip finishing mill is proposed. The change in strip tension, which exerts an influence on the width and thickness of the products, is induced by the looper height variation. Accordingly, it is important to control the looper height precisely. The looper control system may suddenly become unstable due to a change in the characteristics of rolled material and an occurrence of the slip between roll and strip while rolling. In order to maintain the control system stable even under these changes, the robust control system has been developed. However, there remained problems of slow response of the robust controller. The reason is that the control gain is set at a low value to assure the stability for the various kinds of disturbances. To solve the problem, it is necessary to set at the appropriate control gain. In this paper, the estimation of a damping coefficient of the looper height control system is carried out to adapt the control gain according to the damping coefficient. The proposed adaptive controller assures both the robustness and a high control performance regardless of the change in rolling conditions and disturbances. Using this method, the looper height control can guarantee both the stability of the looper height control and the high degree of accuracy in control.

(cf. *ISIJ Int.*, **43** (2003), 358)

Chemical and Physical Analysis

A new method for describing the atomic-scale structure of rusts formed on the iron based alloy surfaces

S.SUZUKI et al.

Quantitative structural analysis by conventional X-ray diffraction and anomalous X-ray scattering coupled with the reverse Monte-Carlo simulation technique has been carried out, in order to characterize the atomic-scale structure of rust formed on the surface of Fe, Fe–2%Cr, Fe–3%Ni and Fe–1.6%Cu alloys and a weathering steel. Rust samples were prepared by filtering corrosion products formed on the surface of these alloys in salt water. X-ray diffraction patterns showed that main components of the rust consist of ferric oxyhydroxides such as γ-FeOOH. Radial distribution functions obtained from both conventional X-ray diffraction and anomalous X-ray scattering clearly indicated that the fundamental local unit structure in the rust is the octahedral FeO_6, although it is likely to be distorted. Realistic atomic arrangements in the rust were estimated by fitting of the ordinary and environmental interference functions calculated using the reverse Monte-Carlo simulation technique. These results provided that the network structure consists of the FeO_6 octahedral units and its distortion depend upon the composition of samples. These facts suggest that alloying elements in the rust, which themselves are corroded, play an important role in forming the atomic-scale structure of the rust.

(cf. *ISIJ Int.*, **43** (2003), 366)

Forming Processing and Thermomechanical Treatment

Mechanical bonding process to manufacture clad materials—divided flow bonding

J.YANAGIMOTO et al.

Basic Characteristic of mechanical bonding process using divided plastic flow is investigated in this paper. This bonding process can be applicable to the bonding of any combination metals such as bonding of aluminum and steel. It could be utilized not only to join structural steels but also to manufacture clad sheet continuously within rolling process. Basic characteristic of proposed bonding process is investigated through a series of bonding experiments using aluminum alloy and plain carbon steel, and effects of geometries of bonding part on divided plastic flow and bonding strength are clarified. Through the investigation, it has become clear that sound bonding of aluminum alloys and steel can be realized under cold forming temperature. Better bonding characteristics could be obtained if we optimize geometry of bonding part.

(cf. *ISIJ Int.*, **43** (2003), 373)

Microtexture of thin gauge hot rolled steel strip

R.PETROV et al.

A series of trials were conducted on a compact rolling mill to evaluate the properties and characteristics of carbon steel strip hot rolled to less than 2 mm in thickness from thin cast slabs. Steels of two different compositions were studied, the first one, a low carbon steel, was rolled to a total reduction

ranging from 94 to 98%, final thickness ranging from 1.06 to 2.69 mm, whereas the second one was a Nb bearing microalloyed steel rolled to a total reduction of around 96%. The rolling trials were complemented by means of computer modelling to get a deeper understanding of the process. It was found that the ferritic grain size of the low carbon strips varied from 7 to 10 μm, with the finer sizes found in the thinner strips, the grain size of the microalloyed steel was found to be 3.6 μm. Analysis of the texture of the hot rolled strips indicated that the ferrite in the low carbon resulted from the transformation of recrystallized austenite, in comparison, low intensity transformation texture from unrecrystallized austenite was found in the Nb bearing steel. The observed texture data correlate with the R-values measured.

(cf. *ISIJ Int.*, **43** (2003), 378)

Surface Treatment and Corrosion

Degradation of high-temperature oxidation resistance for Ni-based alloys by Re addition and the optimization of Re/Al content

M.MONIRUZZAMAN et al.

High-temperature oxidation tests were conducted with two groups of Ni-based superalloys in order to elucidate the Re effect on oxidation resistance. One group of alloys was the Ni–8Cr–2Ti–10Al–Re system, characterized by 10 mol% Al content. The other group of alloys was the Ni–8Cr–2Ti–15Al–Re system, characterized by 15 mol% Al content. The alloy compositions were chosen with the aid of the d-electrons concept, so that any undesirable phases would not appear in the microstructure. Both cyclic and isothermal oxidation tests were carried out at 1 373 K for a total time of 720 ks. The oxidation resistance decreased clearly with increasing Re content in the 10-Al series alloys, but did not in the 15-Al series alloys. The alloys having a Re/Al ratio (mol%) up to 0.1 exhibited very small mass change by oxidation, so the Re/Al ratio was indeed a good indication for the design of superalloys having a good oxidation resistance.

(cf. *ISIJ Int.*, **43** (2003), 386)

Transformations and Microstructures

Effect of undercooling of austenite on strain induced ferrite transformation behavior

S.C.HONG et al.

Hot compression test of up to 70% reduction was performed to examine the effect of undercooling (ΔT=Ae_3−Ar_3) of austenite on strain induced ferrite (SIF) transformation behavior. The undercooling of austenite was controlled by applying various cooling rates from the austenitization temperature to the deformation temperature. In order to examine ferrite formation, the flow curve was measured and compared with the calculated flow stress of austenite. Fine ferrite grains with a size of 2 μm were observed within prior austenite grains. Increasing ΔT was an effective way to increase the amount of SIF, when the applied reduction was relatively small. With heavy deformation, the amount of SIF was nearly the same regardless of ΔT, while ferrite grains became finer and equiaxed by dynamic continuous recrystallization after transformation. It was also found that the amount of reduction for onset of ferrite formation within austenite grain was reduced with increasing ΔT. The decrease of flow stress was observed compared with that of austenite, which was mostly from ferrite formation during the deformation.

(cf. *ISIJ Int.*, **43** (2003), 394)

Influence of primary recrystallization texture through thickness to secondary texture on grain oriented silicon steel

T.KUMANO et al.

It is well known that the sharpness of secondary recrystallized Goss texture ({110}⟨001⟩) is deteriorated by nitriding primary recrystallized sheet on the ordinary grain oriented silicon steel. The cause of this deterioration was investigated. It was found that secondary recrystallization of Dispersed Goss ({110}⟨229⟩) caused the deterioration. From the surface to the central position in the primary recrystallization texture, the intensity of Goss Texture decreased and Dispersed Goss increased. Furthermore, nitriding increased the temperature of secondary recrystallization outset. As a result, the nucleation site of secondary recrystallization might shift to the central position where the circumstance that Dispersed Goss could grow easily is satisfied by the CSL model. This can be explained by using the CSL model with consideration of the intensity, Σ5 and Σ9 coincident orientation of Goss, and Dispersed Goss and assuming that Σ9 boundary is more mobile than Σ5 boundary.

(cf. *ISIJ Int.*, **43** (2003), 400)

The nature and consequences of coherent transformations in steel

J.W.MORRIS et al.

Advanced research on structural steels has recently focused on the improvement of properties through the control of grain size. Grain refinement increases strength *via* the Hall–Petch relation, lowers the ductile–brittle transition by increasing resistance to transgranular cleavage, and reduces hydrogen embrittlement by minimizing interfacial fracture along grain or lath boundaries. However, given their different mechanisms, these properties require slightly different measures of the effective grain size. When the grains are smooth and random, all measures of the effective grain size are roughly equivalent. However, transformations in steel are often crystallographically coherent, producing a martensitic, bainitic or ferritic product that has either a Kurdumov–Sachs (KS) or a Nishiyama–Wasserman (NW) relation to the parent austenite. The 24 KS variants and 12 NW variants divide into three sets of eight, corresponding to the three Bain variants of the fcc→bcc transformation. Grain, packet or block boundaries that separate different Bain variants have significant misorientations of the {100} cleavage planes, but may have only slight misorientations of the {110} slip planes. It follows that grain refinement through coherent transformation is very effective in improving resistance to cleavage fracture and, if the boundary facets are small, to hydrogen embrittlement, but is often relatively ineffective in increasing strength. For this reason, grain refinement for increased strength is best done with incoherent transformations (such as the strain-induced ferrite transformation) while grain refinement for low-temperature toughness or hydrogen resistance is best done with coherent transformations that refine the effective grain size without overstrengthening to unacceptably low ductility.

(cf. *ISIJ Int.*, **43** (2003), 410)

Precipitate stability in creep resistant ferritic steels—experimental investigations and modelling

J.HALD et al.

Predictions of long-term microstructure stability of creep resistant ferritic 9–12% Cr steels up to 200 000–300 000 h at temperatures up to 600–650°C are highly interesting for safe power plant operation. At technically interesting creep conditions the microstructure stability is mainly controlled by the stability of precipitate particles. Predictions of precipitate stability have to rely on i) Microstructure characterisation methods to measure volume fractions and mean particle sizes of individual precipitate types, and ii) Microstructure models to predict the evolution of precipitate volume fractions and mean sizes as functions of temperature, time and applied stress. Characterisation methods, which allow online particle type discrimination in 9–12% Cr steels include energy filtered transmission electron microscopy (EFTEM) and scanning electron microscopy (SEM) with atomic number contrast. Modelling of precipitate stability based on thermodynamic equilibrium calculations and multicomponent diffusion databases is demonstrated. A multi-component coarsening model gives accurate predictions of coarsening rates for MX and Laves phase precipitates in steel P92 with fit values for the interfacial energy in the expected range. For $M_{23}C_6$ carbides in steel P92 the model results in unexpectedly low apparent values for the interfacial energy. Modelling of published data for steel P91 indicate much higher coarsening rates for $M_{23}C_6$ carbides, and the fit value for the interfacial energy is as expected. A possible explanation for the low apparent value of the interfacial energy for $M_{23}C_6$ carbides in steel P92 is the content of boron in the steel.

(cf. *ISIJ Int.*, **43** (2003), 221)

Measurement of dynamic strain aging in pearlitic steels by tensile test

B.M.GONZALEZ et al.

The mechanical behavior of a pearlitic steel was studied by means of tensile tests performed in the temperature interval from 298 to 773 K, at strain rates from 10^{-4} to 10^{-2} s^{-1}, aiming to analyze the role of cementite decomposition in the dynamic strain aging (DSA) phenomena occurring in these steels. Typical features of DSA were observed: serrated flow (the Portevin-LeChatelier–PLC effect), the presence of a maximum and a minimum in ultimate tensile strength and reduction of area *versus* temperature curves, respectively, and a less evident maximum in the yield strength *versus* temperature

curve. Apparent activation energies were calculated based on the onset of the PLC effect, the maximum in ultimate tensile strength and the minimum in reduction of area. Results suggest that changes in mechanical properties associated with DSA in pearlitic steels are related to cementite decomposition. Differences on the phenomenological aspects regarding DSA in pearlitic and in low carbon steels are discussed, based on the kinetics of the process.

(cf. *ISIJ Int.*, **43** (2003), 428)

Mechanical Properties

The properties of 1 500 MPa grade alloy steel with carbide free bainite/martensite mixed microstructures

D.-Y.LIU et al.

The effect of tempering temperature on the combined strength and toughness of a low carbon Mn–Si–Cr steel with the microstructure of martensite or carbide free bainite–martensite (CFB/M) has experimentally been investigated. The study reveals that the presence of CFB in a mixed microstructure retards the softening of the steel during tempering and also retards the tempered martensite embrittlement (TME) onset temperature. The air-cooled CFB/M possesses a better combination of strength and toughness compared with water quenched full martensite after tempering within some intermediate temperature range. Filmy rather than blocky retained austenite was found in the air-cooled CFB/M microstructure. The filmy retained austenite in CFB/M has a good stability. Carbon enriched filmy retained austenite in CFB might improve the toughness of the steel after tempering at intermediate temperature range.

(cf. *ISIJ Int.*, **43** (2003), 433)

Supra-ductile and high-strength manganese-TRIP/TWIP steels for high energy absorption purposes

G.FROMMEYER et al.

The microstructural properties of advanced high strength and supra-ductile TRIP and TWIP steels with high-manganese concentrations (15 to 25 mass%) and additions of aluminum and silicon (2 to 4 mass%) were investigated as a function of temperature (−196 to 400°C) and strain rate ($10^{-4} \leq \dot{\varepsilon} \leq 10^{3\,8} - 1$). Multiple martensitic γ_{fcc} (austenie)→ε^{Ms}_{hcp} (hcp–martensite)→α^{Ms}_{bcc} (bcc–martensite)-transformations occurred in the TRIP steel when deformed at higher strain rates and ambient temperatures. This mechanism leads to a pronounced strain hardening and high tensile strength (>1 000 MPa) with improved elongations to failure of >50%. The austenitic TWIP steel reveals extensive twin formation when deformed below 150°C at low and high strain rates. Under these conditions extremely high tensile ductility (>80%) and energy absorption is achieved and no brittle fracture transition temperature occurs. The governing microstructural parameter is the stacking fault energy Γ_{fcc} of the fcc austenite and the phase stability determined by the Gibbs free energy $\Delta G^{\gamma\to\varepsilon}$. These factors are strongly influenced by the manganese content and additions of aluminum and silicon.

The stacking fault energy Γ_{fcc} and the Gibbs free energy G were calculated using the regular solution model. The results show that aluminum increases Γ_{fcc} and suppresses the $\gamma_{fcc}\to\varepsilon^{Ms}_{hcp}$ transformation, whereas silicon sustains the $\gamma_{fcc}\to\varepsilon^{Ms}_{hcp}$ transformation and decreases the stacking fault energy. At the critical value of $\Gamma_{fcc}\approx 25$ mJ/mol and for $\Delta G^{\gamma\to\varepsilon}>0$, the twinning mechanism is favored. At lower stacking fault energy of ($\Gamma_{fcc}<16$ mJ/mol and for $\Delta G^{\gamma\to\varepsilon}>0$, martensitic phase transformation will be the governing deformation mechanism.

The excellent ductility and the enhanced impact properties enable complex deep drawing or stretch forming operations of sheets and the fabrication of crash absorbing frame structures.

(cf. *ISIJ Int.*, **43** (2003), 438)

Room temperature straining behaviour of iron–silicon aalloys

T.R.-YÁÑEZ et al.

A series of iron–silicon alloys were produced to study the mechanical behaviour at room temperature of alloys ranging from 3.3 to 6.5 wt% Si. Cast samples were machined into compression specimens to be tested in a servo-hydraulic computer driven testing machine at a constant rate of strain, polytetrafluoroethylene tape was used to reduce the effect of friction while testing. Constitutive equations were fit from the stress–strain data. It was possible to establish a relationship between the parameters used in the constitutive formulation and the amount of silicon added. Metallographic observation of deformed specimens revealed the presence of twins in the material. It was found that the twin density increased with the amount of deformation and silicon. A relationship between the stress for saturation and the distance between the twins was established.

(cf. *ISIJ Int.*, **43** (2003), 447)

Plastic deformation andfracture behavior of galvannealed coating

Y.NUNOMURA et al.

Deformation and fracture in galvannealed coating which was subjected to tensile or compressive stress by three point bend test were investigated by scanning electron microscopy. In the coating subjected to compressive stress, cracks were generated in the δ_1 phase and propagated at an angle inclined to coating plane in the δ_1 phase. Then, fracture occurred within δ_1 phase, or, along the Γ–Fe interface. In the coating subjected to tensile stress, cracks were generated in the δ_1 phase and propagated perpendicularly to coating plane in the δ_1 phase. Then, cracks reached and propagated along the Γ–Fe interface. The coating did not show any plastic deformation under tensile stress but showed apparent plastic deformation under compressive stress. During deformation of the coating and the steel substrate, there was substantial interaction and inhomogeneity. Major deformation mode in the coating was cracking while that in the steel substrate was inhomogeneous plastic deformation in the regions adjoining to the cracks, irrespective of compressive or tensile stress.

(cf. *ISIJ Int.*, **43** (2003), 454)

Social and Environmental Engineering

Mechanism of dioxins/furans formation at high temperature in combustion processes

H.KAWABATA et al.

To understand the mechanism of toxic dioxins/furans (Dioxins) formation in incineration processes, the combustion experiments were carried out with an electric furnace in laboratory scale at 1 073 K using mainly the powder of regent grade polyvinyl chloride (PVC powder) as a combustion material under a complete and an incomplete combustion conditions. In addition, the thermodynamic evaluations have been done on the formation and decomposition of Dioxins.

Dioxins are formed even at the combustion temperature of 1 073 K under the conditions in which the fly carbonaceous matters exist. It is supposed that Dioxins are mainly formed on the surface of the fly carbonaceous matters where high CO/CO_2 ratio is established. Dioxins' concentration is correlated with the number of the fly carbonaceous matters in an exhaust gas. The formation/suppression of Dioxins is dependent upon the amount of the fly carbonaceous matters remained in the exhaust gas from the combustion furnaces.

(cf. *ISIJ Int.*, **43** (2003), 461)