（＊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

Observation of inclusions in manganese-silicon killed steels at steel-gas and steel-slag interfaces

S.VANTILT et al.

The behaviour of inclusions on the surface of molten steel and at molten steel–slag interfaces was observed *in-situ* using a Confocal Scanning Laser Microscope (CSLM). Solid irregular and liquid spherical inclusions were observed on the molten steel surfaces. They were found to cluster and agglomerate, driven by capillary depression forces and they were identified as Al_2O_3–MnO-SiO_2, Al_2O_3–MnO and Al_2O_3 particles in quenched samples. At steel–slag interfaces, inclusion clustering was also observed. Here a weak repulsive force was found to oppose fluid flow driven clustering. The inclusions were found to react with the slag and to undergo changes in shape, size and chemistry. Examination of the interface after the experiments revealed that the inclusions were enriched in CaO, SiO_2 and Al_2O_3 from the slag.

(cf. *ISIJ Int.*, **44** (2004), 1)

Modeling and simulation of heat front propagation in the iron ore sintering process

J.MITTERLEHNER et al.

The aim of this work was to develop a model for the iron ore sintering process with special focus on heat front propagation through the packed bed and to provide a powerful tool ("SinterSim v1.1") for the simulation of the sintering process. Special interests were paid to the sub-models of fluid flow through the packed bed, oxidation of carbon monoxide, coke combustion, melting and solidifying of the bed material and the thermal decomposition the of ore components. Base case calculations were done showing very good agreement compared to values gained in test runs of the sintering process in a sinter pot. Numerous calculations with varied parameters were carried out to evaluate the behavior of the sintering process in means of a sensitivity coefficient for the specific variation. For duration of the sintering process and height of the sintering zone the most sensitive parameters turned out to be the mean diameter of the sinter mix material, void fraction inside the packed bed, the amount of coke breeze in the bed, the humidity of the green sinter mix and the amount of Fe_2O_3 in the ore.

(cf. *ISIJ Int.*, **44** (2004), 11)

Thermodynamics of phosphorus in the MnO–SiO_2–Fe_tO system

Y.KOBAYASHI et al.

Phosphorus, one of typical impurities in steel, has been traditionally tried to be removed to the refining slag in the conventional steel making process. On the other hand, the inverse-utilization of impurities in steel was introduced recently to provide a resource circulating society. In these processes, phosphorus can be and must be restored in the steel during the deoxidation and solidification. The usage of elements with high deoxidizing and low dephosphorizing abilities such as manganese and silicon will be beneficial for obtaining such kind of steel. However, the thermodynamic behavior of phosphorus in such oxide fluxes has not been established. Therefore, the phosphate capacity as the phosphorus containing ability for the MnO–SiO_2–Fe_tO system, one of the typical slags for deoxidation, has been investigated by measuring the phosphorus partition between the slag and solid or molten iron. The phosphate capacities for the present system were determined to be from 8.5×10^{14} to 3.8×10^{18} at temperatures from 1 673 to 1 923 K. The present system has shown a much smaller phosphate capacity by several orders of magnitude compared to the conventional CaO bearing systems and provides the estimation of a very low phosphorus distribution ratio between the slag and the steel. In addition, the heats of the phosphate formation reaction were derived from the temperature dependence of phosphate capacities.

(cf. *ISIJ Int.*, **44** (2004), 21)

Numerical analysis of reactions in a cupola melting furnace

H.SUN et al.

Composition variations of metal and slag in a cupola melting process were investigated by a reaction model for gas/liquid iron/coke and slag/liquid iron systems. A significant amount of alloy elements is lost due to the gas oxidation in furnace shaft. Carbon in metals is determined by gas oxidation and carbon pickup from coke in the shaft. Manganese and silicon are mainly lost by gas oxidation in shaft. Sulfur increases in shaft by pickup from coke but decreases in siphon by slag desulphurisation. There is no significant phosphorus change in shaft, but phosphorus increases in siphon. Oxides formed in shaft contribute 20% of total tapped slag, in which SiO_2 contribute 40% of total SiO_2 in the tapped slag.

(cf. *ISIJ Int.*, **44** (2004), 27)

Physical simulation of impurity removal through submerged liquid slag injection in steel melt

S.GHORAI et al.

With the increase in demand for quality steel having very stringent compositional control, the secondary steelmaking has become one of the significant developments in the steel making technology during the past few decades. Injection of powder with inert carrier gas is commonly practiced in industry to decrease the impurity contents of steel in a more economical way. Such high temperature metallurgical operations are mass transfer controlled and accordingly the design and operating parameters have significant roles to play. However, powder particles can only penetrate partially to the liquid melt while most of the particles ascend through the melt as "particles inside the bubble" in the semi-solid state without contributing much to mass transfer. In this regard submerged liquid slag injection may be considered as a potential area of investigation. In the present study, simulation of the submerged liquid slag injection in steel melt has been carried out using a cold model in the laboratory. Relative contributions of the transitory to permanent contact reactions have been estimated from several experimental data in conjunction with the mathematical model proposed by Ohguchi and Robertson. The present results show that mass transfer rate increases with increase in gas flow rate, liquid injection rate and lance depth. An empirical correlation for overall mass transfer rate constant as a function of gas flow rate, oil injection rate and lance depth has been developed. The present result also indicates that transitory contribution increases significantly with increase in gas flow rate.

(cf. *ISIJ Int.*, **44** (2004), 37)

Molecular dynamics analysis of three-dimensional anionic structures of molten Al_2O_3–Na_2O–SiO_2 system

Y.SASAKI et al.

For the molten Na_2O–SiO_2–Al_2O_3 system, the distributions of Al^{3+} ions in the various complex anions and the interconnected relations between the Si tetrahedra and Al tetrahedra consisted of the complex anions have been studied by molecular dynamics simulation and Raman spectroscopy. From the interconnected relations between Si and Al tetrahedra calculated by the molecular dynamics simulation, the abundance of complex anions was evaluated. Based on the abundance of these anions, the degree of polymerization in Na_2O–SiO_2–Al_2O_3 melts was found to be enhanced by the substitution of Al_2O_3 for SiO_2. The Raman spectroscopic band at around 520 cm^{-1} related to the three-dimensional network structure was found to develop with the replacement of SiO_2 by Al_2O_3 under the constant Na_2O content. Based on these results by molecular dynamics simulation and Raman spectroscopic measurements, it was confirmed that the Al^{3+} ion had a strong preference to enter the three-dimensional network structure.

(cf. *ISIJ Int.*, **44** (2004), 43)

New calibration technique for X-ray absorption studies in single and multiphase flows in packed bed

M.G.BASAVARAJ et al.

An X-ray technique has been developed to determine the concentration and liquid holdup in a packed bed. To quantify these parameters in single and multiphase flow systems, at local level, a calibration method/graph has been developed. This graph has also been used to obtain the local concentration value of a liquid in presence/absence of another miscible liquid in a porous media. The same graph has been used to quantify the local liquid holdups (static and dynamic) in a packed bed. The same technique can be used for other radiological methods such as gamma rays and neutron radiography. Results obtained from this technique are in agreement with the published data.

(cf. *ISIJ Int.*, **44** (2004), 50)

Ironmaking

Effect of processing parameters on the swelling behaviour of cement-bonded briquettes

M.SINGH et al.

The use of cement-bonded agglomerates of iron-

rich by-products generated in iron and steel plants as burden material for blast furnaces is becoming quite common. It has been observed that under certain conditions the briquettes containing pellet-fines show a tendency to swell catastrophically when reduced at 900–1 000°C using carbon monoxide as a reducing agent. This swelling is dependent upon a number of processing parameters, such as: composition of briquettes, particle size of raw material, amount of cement, composition of cement, and coke content. It is not dependent upon the size of agglomerate or hydration period. From the optical micrographs, it is apparent that the swelling may be attributed to the formation of small spheroidal iron particles that move apart, thereby causing swelling. This paper describes the effect of various processing parameters that cause the abnormal swelling in cement-bonded briquettes made of pellet-fines.

(cf. *ISIJ Int.*, **44** (2004), 59)

Improving the oxidizing kinetics of pelletization of magnetite concentrate by high press roll grinding

G.QIU et al.

In this paper the effect of the high press roll grinding (HPRG) on the oxidizing kinetics of the pelletization of magnetite concentrate was investigated, which aims to improve the pelletability of the concentrate. The comparison of the roasted pellet strength at various process parameters of roasting system with or without using the HPRG was also conducted. It is shown that the rate of oxidation of magnetite into hematite increases during the roasting of the green pellets made by using the HPRG to pretreat the concentrate, and the apparent activation energy of the oxidation reaction of magnetite is reduced from 49.62 kJ/mol to 33.87 kJ/mol in the range of 650–950°C, which results from the marked increase in specific surface area and the occurrence of lattice deformation of magnetite concentrate by the HPRG's mechano-chemical activation. Under the optimum roasting conditions of preheating at 950°C for 15 min and indurating at 1 250°C for 15 min, the compressive strength of product pellets is raised from 3 490 to 4 540 N per pellet by using the HPRG to replace damp mill to pretreat the concentrate. The improved kinetics of oxidation of magnetite concentrate agrees well with the enhancement of mechanical strength of roasted pellets.

(cf. *ISIJ Int.*, **44** (2004), 69)

Effects of preoxidation of titania–ferrous ore on the ore structure and reduction behavior

E.PARK et al.

The paper examined an effect of preoxidation of titania-ferrous ore (New Zealand ironsand) on the ore structure and reduction by carbon monoxide.

The major phase in ironsand is titanomagnetite, Fe_3O_4–Fe_2TiO_4 solid solution, with spinel cubic structure. In the non-isothermal pre-oxidation titanomagnetite was oxidized to cubic maghemite and then transformed to rhombohedral titanohematite, Fe_2O_3–$FeTiO_3$ solid solution. Isothermal preoxidation of the ironsand at 1 273 K transformed titanomagnetite to titanohematite and partly to pseudobrookite (Fe_2TiO_5), however, complete oxidation of Fe^{2+} to Fe^{3+} in titanomagnetite was not achieved in the experimental condition.

The reduction of the titania–ferrous ore was investigated in non-isothermal and isothermal experiments using 75vol%CO–25vol%Ar gas mixtures in a laboratory fixed bed reactor. Samples in the course of reduction were characterized using XRD and EPMA. Preoxidation increased the rate of ironsand reduction.

(cf. *ISIJ Int.*, **44** (2004), 74)

Steelmaking

Mixing evaluation in the RH process using mathematical modelling

S.K.AJMANI et al.

Mixing phenomena in a RH process has been studied numerically by solving the Navier Stokes equations along with the species concentration equation in a cartesian coordinate system comprising the geometry of the ladle and the snorkel fitted to it. The solution of the species concentration equation has been utilized to compute the mixing time in the RH ladle under different flow conditions. The numerical procedure and solution algorithm has been first verified by comparing the numerically obtained tracer dispersion curve, with the actual plant measurement, which agrees fairly well with each other. Mixing time for the RH process has been computed for different downleg snorkel size, snorkel immersion depth (SID) and steel velocity within the downleg and a non-dimensional mixing time correlation has been developed for the RH ladle taking the above three pertinent input parameters into considerations. The correlated non-dimensional mixing time equation predicts fairly well the computed result as well as the actual mixing time being observed in the plant.

(cf. *ISIJ Int.*, **44** (2004), 82)

Supersonic O_2-jet impingement on liquid iron with surface chemistry

D.NAKAZONO et al.

This paper describes numerical analysis of a supersonic O_2-jet impingement on carbon-contained liquid iron under vacuum circumstances. The gas phase is assumed to be composed of O_2, CO, CO_2, O and C. Since gas temperature is elevated over 1 000 K in the vicinity of the surface of liquid iron, high-temperature gas effects, namely vibrational energy excitation and dissociation, are included in the analysis. Therefore, the flow field is expressed by Navier–Stokes equations consisting of mass conservation, momentum, overall energy, vibrational energy and species mass conservation equations. Furthermore, surface reactions for O_2–C and O–C encounters are included in surface boundary conditions. Cavity geometry is determined from the balance of pressure, shear stress, surface tension and liquid buoyancy. Based on the numerical results, sensitivity of mass fraction for each species to the probability of surface reaction is discussed. In addition, the effect of the surface reactions on the cavity geometry is clarified.

(cf. *ISIJ Int.*, **44** (2004), 91)

Casting and Solidification

Large eddy simulation of turbulent flow with the effects of DC magnetic field and vortex brake application in continuous casting

Z.-D.QIAN et al.

Vortexing flow exists in the free surface of molten steel in the slab continuous casting process and leads to uncleanness of steel. A large eddy simulation (LES) model has been developed to simulate the vortexing flow phenomena with the effect of DC magnetic field and vortex brake application in the slab continuous casting process. The influence of the submerged entry nozzle (SEN) port angle and the SEN depth to the turbulent vortex was analyzed and the mechanism of the turbulent vortex and the biased vortex formation was found. The vortexing flow is the result of shearing of the two unsymmetric surface flows from the mold narrow faces when they meet adjacent to the SEN. The unsymmetric surface flow comes from the unsymmetric upward re-circulating flow, which is caused by turbulent energy of the fluid for turbulent vortex and caused by biased flow and the turbulent energy of fluid for biased vortex. The new vortex brake can eliminate the turbulent vortex and suppress the biased vortex significantly by removing the downward component of the vortexing flow. When the magnetic field is located at the free surface, the turbulent vortex and the biased vortex can be eliminated.

(cf. *ISIJ Int.*, **44** (2004), 100)

Chemical and Physical Analysis

Application of pulsed voltage to d.c. glow discharge plasma for controlling the sputtering rate in glow discharge optical emission spectrometry

K.WAGATSUMA

The application of a pulsed voltage to a Grimm-style glow discharge lamp was investigated to control the sputtering rate in d.c. glow discharge optical emission spectrometry. This purpose is to reduce the sampling depth so that thin film-like samples can be measured with a better spatial resolution and a better analytical precision. While the sputtering rate decreases by using a pulsed voltage due to the reduction in the effective discharge power, the emission signals from the glow discharge plasma are modulated by a cyclic variation of the discharge voltage so that only the desired signals can be detected without any noises with a lock-in amplifier. Whereas the sputtering rate could be more than 50% reduced when the duty ratio of the pulsed voltage was down to 20% compared to the rate in the corresponding continuous discharge, the emission intensities could be estimated with much better signal-to-noise ratios.

(cf. *ISIJ Int.*, **44** (2004), 108)

Forming Processing and Thermomechanical Treatment

Aging behaviour in copper bearing high strength low alloy steels

A.N.BHAGAT et al.

Strengthening due to precipitation of copper and

microalloying elements is a phenomenon utilized in the design of some HSLA steels for naval structural applications. In the present work, precipitation of copper and associated property changes during aging of three Cu-containing HSLA steels were investigated. Electrical resistivity change during isothermal aging of one low carbon steel was compared with that for HSLA steels with a view to evaluate the kinetics of copper precipitation in the later. The results fitted to Johnson–Mehl–Avrami equation indicate that this precipitation occurs in two consecutive stages with activation energy in the range of 114–128 kJ/mol and 64–77 kJ/mol, respectively. These values suggest a dominant role of the high dislocation density of the martensite matrix in the aging process. The peak hardness during isochronal (1 h) aging was observed in the aging temperature range of 500–550°C, whereas Charpy impact toughness was lowest for the samples aged at 450°C. The fractographs of the Charpy specimens were in good agreement with the impact strength measurements, apparently indicating an adverse effect of coherent copper precipitates on the impact properties.

(cf. *ISIJ Int.*, **44** (2004), 115)

Simulation of hammering hydroforming by static explicit FEM

T.HAMA et al.

Recently, tube hydroforming is receiving increasing attention. Knowledge on the process is, however, still insufficient to produce high-quality products in an efficient way. Hammering hydroforming, in which the hydraulic pressure is pulsated synchronously with axial feeding, is an effective method of improving forming ability. However, the factors that cause the improvement are still unclear. In the research reported in this paper, simulations of an automotive component produced by hammering hydroforming have been performed using a static explicit finite-element method code, which was developed in this study. The simulation results showed a good agreement with the experiment, thus validating the hammering hydroforming simulation by the developed code. The factors that improve the forming ability were also investigated by simulation. It was clarified that the hammering forming has the advantage of obtaining enough expansion as well as the regular forming with the lower friction force by using the lower pressure history. Moreover, that roughly the same effect as lowering the friction coefficient could be achieved by the hammering hydroforming.

(cf. *ISIJ Int.*, **44** (2004), 123)

Surface Treatment and Corrosion

Effect of galvanising parameters on spangle size investigated by data mining technique

M.DUTTA et al.

Development of flowery patterns or spangles on the surface of hot dip galvanised steel sheets is a common phenomenon. While elements like lead and antimony are known to be the primary factors contributing to spangle formation, sometimes they grow uncontrollably small or big. In this study, a data mining approach has been used to find a correlation between the spangle size in galvanised sheets, and the process parameters at one of the continuous galvanising lines at Tata Steel. All the process related data were collected from the CRM database, while the information on spangle size was generated through actual measurements. Statistical (factor analysis) and mining (neural classification mining) analyses were carried out. The most significant input variables with respect to spangle size were extracted. The artificial neural network classification model was developed using 849 records for training with a prediction accuracy of 57%. Strip thickness appears to be most sensitive on the spangle formation; whereas lead and antimony concentration in zinc bath, and the pressure difference between the top and bottom air knives seem to be more sensitive amongst the other eight significant parameters. The classification model can be used for prediction of spangle size given the process parameters. It can also be used as an important tool to set and adjust the process parameters to produce a given spangle size.

(cf. *ISIJ Int.*, **44** (2004), 129)

Behaviour of Mn and Si in the spray powders during steam oxidation of Ni–Cr thermal spray coatings

T.SUNDARARAJAN et al.

Steam oxidation resistance of 80Ni–20Cr and 50Ni–50Cr coatings has been evaluated in our previous study. The coatings were HVOF sprayed onto the modified 9Cr–1Mo steel substrate and the Cr content in the coating played an important role on the steam oxidation resistance. In the present study, effects of Mn and Si present in the powder and hence incorporated into the coatings were studied. In the 80Ni–20Cr coating, Mn segregated to the coating surface during steam oxidation duration of 1 000 h. Si also enriched at the surface of the coating. On the other hand, the 50Ni–50Cr coatings showed the absence of either Mn segregation or Si enrichment in the post-steam oxidized specimen. The results are discussed in conjunction with the diffusion of Mn and Si onto the chromium oxide layer at high temperatures and the influence of Cr content on the diffusion characteristics of these minor elements.

(cf. *ISIJ Int.*, **44** (2004), 139)

The sulfur effects on high-temperature oxidation of an alumina-forming heat-resistant alloy

T.AMANO et al.

High-temperature oxidation behavior of Fe–20Cr–4Al alloys with small amounts of sulfur (1–6 300 ppmS) was studied in oxygen for 18 ks at 1 273, 1 373, 1 473, 1 573 and 1 673 K by mass-change measurements, X-ray diffraction, scanning electron microscopy, and electron probe microanalysis. Spalling of the scales on all of the alloys was not observed after oxidation at 1 273 K. The scales on the 4 and 7 ppmS spalled from the entire surface after oxidation at 1 373 K, however, the scales on the other alloys did not spalled. Intensive spalling of scales was observed for the 4, 7, 35, and 53 ppmS after oxidation at 1 473 K, and that of scales was recognized for the 4, 7, 35, 53 and 104 ppmS after oxidation at 1 573 K. On the other hand, after oxidation at 1 673 K, intensive spalling of scales was observed for the 4, 7, 1 300 and 6 300 ppmS. Spalling of scales on the alloys depends on sulfur content and oxidation temperature. The mass gain of these alloys tended to increase with increasing sulfur content. The scales formed on all the alloys were α-Al_2O_3. The scale/alloy interface changed from planar to convoluted morphologies with increasing sulfur content after oxidation at 1 673 K. Sulfur in the alloys with more than 7 ppmS existed all over the matrix as chromium-sulfide particles, and then moved to the oxide-alloy interface during oxidation.

(cf. *ISIJ Int.*, **44** (2004), 145)

Transformations and Microstructures

Re-dissolution of VN during tempering in high chromium heat resistant martensitic steel

M.TAMURA et al.

Precipitation behavior of VN during isothermal tempering at 740–800°C of 7%Cr–0.4%V–0.09%N steel (% denotes mass%, hereinafter) has been studied. Initially, rapid softening takes place accompanied by the precipitation of VN and, after that, the quasi-steady state in a hardness *vs.* tempering time diagram is continuing for a while. After the quasi-steady state, re-dissolution of VN particles rapidly occurs followed by final precipitation of VN. Just before the peak time of the re-dissolution of VN particles, both the temporal decrease in hardness and the temporal increase in the integral breadth of an X-ray diffraction peak take place. The similar precipitation phenomenon is confirmed in 0.14%C–9%Cr–1%Mo–0.2%V–0.09%Nb steel. In both steels the re-dissolution of VN or NbC (hereinafter MX) accompanies the decomposition of martensite. The following reactions are suggested as a mechanism for the re-dissolution of MX type particles: local stresses induced by the recovery of martensite unlock the pinning of dislocations by the MX type particles and the consequent isolated particles, which become energetically unstable, are re-dissolving into the matrix.

(cf. *ISIJ Int.*, **44** (2004), 153)

The kinetics of static recrystallization in microalloyed hypereutectoid steels

A.M.ELWAZRI et al.

Compression tests were conducted in order to study the static recrystallization kinetics of hot deformed austenite in hypereutectoid steels containing 1% carbon with different levels of vanadium and silicon. Tests were performed over a temperature range of 875 to 1 100°C using strain rates of 0.01, 0.1 and 1 s^{-1}. Graphs of the recrystallized fraction *versus* time were used to quantify the kinetics of the strain-induced precipitation and generate the precipitation temperature time diagrams for the three steels. A kinetic model for static recrystallization is proposed which takes the V and Si concentrations into account.

(cf. *ISIJ Int.*, **44** (2004), 162)

Effect of Mn and Si addition on microstructure and tensile properties of cold-rolled and annealed pearlite in eutectoid Fe–C alloys

W.FU et al.

The microstructures and tensile properties of cold-rolled and annealed pearlite in Fe–0.8mass%C alloys with various contents of Mn and Si were investigated. With the addition of Mn and Si, the tensile strength (TS) and yield strength (YS) of cold-rolled and annealed pearlite were vastly improved, but its effect on ductility of the cold-rolled pearlite is negligible. The addition of Si is quite effective in improving the ductility of cold-rolled and annealed pearlite, especially when the strength is at a higher level, *i.e.*, lower annealing temperature or shorter annealing period. The optimal tensile properties in the alloys with Mn or Si were obtained after annealing at 723 K for short annealing periods (30 to 120 s). The combined addition of Mn and Si is more effective in improving the tensile properties of cold-rolled and annealed pearlite.

(cf. *ISIJ Int.*, **44** (2004), 171)

Analysis of the trip effect by means of axisymmetric compressive tests on a Si–Mn bearing steel

A.AIROD et al.

Analysis of the TRIP-effect has been implemented by means of series of axisymmetric compressive tests on a Si–Mn bearing TRIP-assisted steel heat treated to vary the amount of retained austenite from 5.70 to 9.11%. The cylindrical samples were deformed with true strains of 0.25, 0.5 and 1, and constant strain rate of 0.1 s^{-1} at room temperature. Microstructural examination of the samples indicates that most of the deformation is sustained by the weakest phase, ferrite. The stress–strain data was fitted to different constitutive equations to evaluate the point at which the TRIP-effect triggers. The results showed that the amount of retained austenite is reduced with the increase of strain. No complete transformation of austenite was found to occur as a fraction of austenite remains untransformed even at equivalent strains as high as one. The behaviour of samples with different amounts of retained austenite, but of equal carbon content, was found to depend on the volume fraction of this structure. It was found that the TRIP-effect was triggered at lower strains, but higher stresses, as the amount of this phase increased.

(cf. *ISIJ Int.*, **44** (2004), 179)

Fragmentation of orientation within grains of a cold-rolled interstitial-free steel

M.D.NAVE et al.

The formation of a favourable recrystallization texture in interstitial-free (IF) steels depends on the availability and activation of particular nucleation sites in the deformed microstructure. This paper presents a description of the deformed microstructure of a commercially cold-rolled IF steel, with particular emphasis on the microstructural inhomogeneities and short-range orientational variation that provide suitable nucleation sites during recrystallization. RD-fibre regions deform relatively homogeneously and exhibit little short-range orientational variation. ND-fibre regions are heavily banded and exhibit considerable short-range orientational variation associated with the bands. While the overall orientational spread of ND-fibre grains frequently is about the ND-axis, the short-range orientational variation often involves rotation about axes in the TD–ND plane that are nearer to the TD than the ND.

(cf. *ISIJ Int.*, **44** (2004), 187)

Stacking faults and transformation of γ' metastable precipitates in an Fe–29Ni–22Co–4Nb–2Cr–1Ti–0.5Al–0.5Si alloy

K.KUSABIRAKI et al.

In this study, we investigate an Fe–29Ni–22Co–4Nb–2Cr–1Ti–0.5Al–0.5Si heat resistant alloy (refer to herein as alloy 929C), in which the γ' phase is the precipitation-strengthening phase. The specimens of alloy 929C are solid-solution heat treated and aged within a temperature range of 993 to 1 073 K for up to 1 440 ks. The morphological and structural changes of the precipitates in the alloy are analyzed by transmission electron microscopic observation. Internal-fringe contrast, which suggests the existence of stacking faults on the $\{111\}_{\gamma'}$ plane, is found in many of the large γ' precipitates formed in the specimens at the latter stage of aging at temperatures above 1 033 K. The metastable γ' precipitates, of which some have stacking faults, are gradually transformed into a stable η phase during aging. The effects of stacking faults introduced by cold-rolling into the γ' particles on the formation of η phase are studied by subsequent annealing heat treatments. The selected-area electron diffraction (SAED) patterns of the cold-rolled and annealed particles show that the metastable γ' precipitates with stacking faults are transformed intensively into a stable η phase. In this paper, we discuss in detail the basis of these morphological and structural changes of the precipitates in heat-resistant alloys.

(cf. *ISIJ Int.*, **44** (2004), 197)

Mechanical Properties

Effect of hydrogen on toughening of a low alloy steel

S.K.SINGH et al.

A low alloy steel containing 0.10C, 0.25Si, 0.87Mn, 0.56Cr, 0.47Ni, 0.21Mo, 0.023S and 0.01P (mass%) was cold rolled to 1.6 mm thick sheets and recrystallised at 700°C to get ferrite grains of 8, 21.5 and 32.5 μm with a random distribution of some spheroidal carbide particles and a few inclusions. Tensile specimens prepared from these sheets were cathodically charged in 1 N NaOH and 0.1 N H_2SO_4 solutions for periods varying from 2 to 24 h, with a current density of 50 mA/cm^2. Tensile tests were carried out with a cross-head velocity of 1.2 mm/min, fracture surfaces were examined by SEM and the deformed structure was examined by TEM. The increase in hydrogen content, up to certain limit, has been effective to cause an increase in both ultimate tensile stress and % elongation resulting a toughening of the steel, while the work hardening is not remarkable. Increase in the ferrite grain size has been observed to enhance this effect. The tensile behaviour has been correlated with observed fracture characteristics and dislocation sub-structure in the ferrite matrix. The toughening effect has been explained in the light of dislocation solute interactions and the damage caused by hydrogen.

(cf. *ISIJ Int.*, **44** (2004), 203)

True stress–true strain relations with very low strain rates at room temperature for an austenitic 25Cr–19Ni steel

N.TSUCHIDA et al.

True stress (σ)–true strain (ε) relations at very low strain rates at room temperature are compared in creep and tensile tests to investigate the effect of deformation history on the σ–ε relation and the applicability of the Kocks–Mecking (KM) model for the austenitic 25Cr–19Ni steel. Experimental results obtained by the creep and the tensile tests indicate that the σ–ε relation is not influenced by prior deformation history at true strains below 0.2. The σ–ε curves at very low strain rates between 10^{-8} and 10^{-10} s^{-1} obtained by the creep test are in accordance with those calculated by the KM model as well as that measured by the crosshead-arresting test. The KM model is concluded to be applicable to the σ–ε relations at very low strain rates obtained by various deformations.

(cf. *ISIJ Int.*, **44** (2004), 209)