（＊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

Rapid mixing and separation of molten slag and metal using cylindrical and baffled vessels suddenly set in rotation

T.SUGIMOTO et al.

Model investigation was experimentally made of transient liquid flow phenomena of stratified two liquid layers contained in a cylindrical vessel suddenly set in rotation. Transient flow in a baffled vessel was also mentioned to seek a possibility of rapid mixing and separation of molten slag and metal and to develop a novel refining process. The effects of the vessel size and the physical properties on the flow in the transient period were clarified. Particular attention was paid to a change in the interfacial area which is one of the most influential parameters for the refining process. Empirical equations were proposed for the flow establishment time.

(cf. *ISIJ Int.*, **43** (2003), 1867)

Fusion behaviour of synthetic aluminothermic ferro-chrome slags

U.K.MOHANTY et al.

Fusion behaviour of synthetic slags resembling those produced during Alumino-thermic reduction of chromite ore for production of Low-carbon ferro-chrome has been thoroughly discussed.

The effect of fluxes like CaO, MgO and CaF_2 on the measured values of the characteristic temperatures, which represent the fusion behaviour of a slag, has been experimentally determined and critically discussed.

All the three fluxing constituents are found to decrease the characteristic temperatures. CaF_2 is found to decrease the gap between the liquidus temperature and the temperature characterising the flow of the slag.

(cf. *ISIJ Int.*, **43** (2003), 1875)

Production of niobium powder by magnesiothermic reduction of feed preform

T.H.OKABE et al.

To develop an effective production process of niobium powder, a new preform reduction process (PRP) based on the magnesiothermic reduction of feed preform containing niobium oxide (Nb_2O_5) was investigated. The feed preform was fabricated from slurry, which was made by mixing Nb_2O_5 powder, flux (*e.g.*, $CaCO_3$) and binder. Various compositions of preform in the form of plates were prepared using a conventional technique, and the fabricated preform was heated at 1 273 K before reduction in order to remove the binder and water. The sintered solid preform containing Nb_2O_5 was then placed in a stainless steel container, and made to react with magnesium vapor at a constant temperature, ranging between 1 073 and 1 273 K, for six hours. Niobium powder was recovered from the reduced preform by acid leaching. Niobium metal powder with 99 mass% purity was obtained as a result. This process was found to be suitable for producing a homogenous fine powder, when the composition of flux, and reduction conditions are controlled.

(cf. *ISIJ Int.*, **43** (2003), 1882)

Proposal of a novel agitation method using swirl motion of molten metal jet

J.YOSHIDA et al.

When a liquid was injected into a cylindrical bath of the same liquid through a centered bottom nozzle, a liquid jet was formed above the nozzle. The jet did not always rise straight upward, but exhibited a swirl motion under a certain condition. The bath was strongly agitated in the presence of the swirl motion. A molten metal jet also can be generated using a potential energy difference between two vessels containing the molten metal. The occurrence of the swirl motion is therefore useful for the development of a novel refining process. As a first step of this research series, the critical condition for the occurrence of the swirl motion, the swirl period and the amplitude were investigated in this study. Empirical equations for the period and amplitude were proposed.

(cf. *ISIJ Int.*, **43** (2003), 1890)

Structural analysis of molten Na_2O–NaF–SiO_2 system by Raman spectroscopy and molecular dynamics simulation

Y.SASAKI et al.

To determine the effect of F ions on the structure of the molten alkali silicate systems, quenched Na_2O–SiO_2–NaF systems were investigated by Raman spectroscopy and molecular dynamics simulation. The systematic increase of 1 100 cm^{-1} band intensity in the Raman spectra of the silicate melts accompanying the replacement of O by F provides the evidence for concomitant polymerization of melts. From the molecular dynamics simulation, it was confirmed that most of substituted F was mainly coordinated to Na^+ ions but not Si^{4+} ions at least up to 12.5 mol% of F ion content. A small amount of F was found to be coordinated to Si as a non-bridging ion from the molecular dynamics simulation, although there was no recognizable evidence from Raman spectroscopy. These results were consistent with the mechanism in which F associated with otherwise network-modifying Na rather than with network-forming Si. Since F was associated to Na^+ ions, the replace of O ion by two F ions promote the polymerization of silicate melts.

(cf. *ISIJ Int.*, **43** (2003), 1897)

Ironmaking

Reduction behavior of carbon composite iron ore hot briquette in shaft furnace and scope on blast furnace performance reinforcement

Y.MATSUI et al.

The reduction and melting behavior of carbon composite iron ore hot briquette in shaft furnace are discussed. As these agglomerates are made by the use of thermal plasticity of coal, the reduction rate by chain reactions in interface between ore and coal could be increased. The carbon composite iron ore hot briquettes achieve 95% reduction degree in about 10-min descent time to the 1 100°C heat reserve zone bottom end and the drop of molten iron temperature is kept to 20°C. As a result, it is expected that these new agglomerates could decrease the fuel rate and discharging amount of CO_2 as well as have a possibility of extension of furnace life. Finally the paper ends by shaping the future of blast furnace on environmental phases for the new century. Especially,it is expected that carbon composite iron ore hot briquette lowers temperature of heat reserve zone and shortens the length, suggesting the possibility of shortening of the reserve zone (inactivity zone), that is, shortening of the blast furnace height.

(cf. *ISIJ Int.*, **43** (2003), 1904)

The effect of additives and reductants on the strength of reduced iron ore pellet

R.C.GUPTA et al.

The higher strength of directly reduced iron (DRI) in pellet form is useful in handling, storing and charging from height without breakage. The DRI pellets commonly exhibit 60 kg cold crushing strength. In this work the effect of reduction temperature, sintering time, quantity/quality of additives and manner of reduction by solid reductant has been studied. The reduced pellet strength could be increased by improving metallic bonds by offering higher reduction temperature (max. 1 250°C) and subsequent sintering. The strength was found to increase by adding slag forming constituents *e.g.* bentonite. The strength of reductant mixed reduced pellet was observed to be affected by the nature of reductant. The reductant with low bulk density and lower carbon content provided higher voidage rendering lower strength. The cold crushing strength (CCS) of reduced pellets observed in this study ranged from 5 to 200 kg exhibiting ductile to brittle behaviour during deformation.

(cf. *ISIJ Int.*, **43** (2003), 1913)

Recovery of magnetite from leached laterite-residue by magnetic separation

H.PURWANTO et al.

In order to improve the grade of iron, upgrading of laterite ore was conducted using wet low intensity magnetic separator. The ore was treated through selective reduction followed by sulphuric acid leaching to recover nickel while iron remained in residual solid. The Vibrating Sample Magnetometer measured the magnetic properties of the ore, as a fundamental of magnetic separation. Magnetic separation was carried out using a Davis Tube Tester. The effect of pretreatments on the magnetization and magnetic separation were investigated.

The results showed that the ore has similar magnetic property with goethite. The heating of the ore at 673 K did not improve significantly on its properties whether goethite changes to magnetite. However, the reduction treatment increased the magnetic properties of the ore due to the formation of magnetite. The magnetic susceptibilities of the original, heated and reduction treated laterite ores were 2.36×10^{-5}, 2.18×10^{-5} and $2\,357\times10^{-5}$ emu/g, respectively. The correlation between magnetite content and magnetization of the magnetic concentrate was showed in a linier equation, which could be

used for the prediction of magnetite content in the sample based on its magnetization. Magnetic separation was applied only to recover iron from the laterite ore after being treated by the selective reduction in which magnetite was produced. About 93.9% of magnetite was upgraded from the laterite ore with 90% of recovery was obtained. The relatively high iron content in the magnetic concentrate indicated a potential use as raw material for iron making.

(cf. *ISIJ Int.*, **43** (2003), 1919)

Liquid holdup in non-wetting packing with lateral gas injection

G.S.GUPTA et al.

The liquid holdup study has been carried out on a two-dimensional cold model under non-wetting condition with lateral gas injection as it is done in the blast furnace. Non-dimensional numbers for both, cold model and blast furnace have been determined. The measurements of static and dynamic liquid holdups were made under different gas and liquid flow rates using two particulate materials of various diameters. Few experiments were performed under dry and wet bed conditions to ascertain the effect of bed history. Holdups results have been compared with the existing correlations available in the open literature. It is found that existing correlations are unable to predict the correct liquid holdup under the blast furnace conditions.

(cf. *ISIJ Int.*, **43** (2003), 1927)

Steelmaking

Measurement of thermopotential of Cu and Sn-containing steels

V.TELEPNEV et al.

The Seebeck effect offers the possibility of rapid analysis of the chemical composition of iron and steels. In this paper, the thermal electromotive forces (TEMF) were experimentally determined in the range of 0.05–0.4%Cu and 0.01–0.1%Sn, respectively, for pure iron and Cr–Ni alloys at different temperatures. The intention is to provide basic data for direct measurement of the contents of the tramp elements Cu and Sn. The thermal EMF measurements were made in an open Tammann furnace under streaming argon gas at rising and falling temperatures. It is demonstrated that reproducible relationships exist between thermal EMF and the content of tramp elements in Fe-based alloys. The contents of Cu and Sn in Fe-based alloys are a linear function of the thermal EMF and temperature.

(cf. *ISIJ Int.*, **43** (2003), 1936)

Chemical and Physical Analysis

Chemical analysis of powdered metallurgical slags by X-ray fluorescence spectrometry

L.Lu et al.

Slag composition determines the physical and chemical properties as well as the application performance of molten oxide mixtures. Therefore, it is necessary to establish a routine instrumental technique to produce accurate and precise analytical results for better process and production control. In the present paper, a multi-component analysis technique of powdered metallurgical slag samples by X-ray Fluorescence Spectrometer (XRFS) has been demonstrated. This technique provides rapid and accurate results, with minimum sample preparation. It eliminates the requirement for a fused disc, using briquetted samples protected by a layer of Borax®. While the use of theoretical alpha coefficients has allowed accurate calibrations to be made using fewer standard samples, the application of "pseudo-Voight" function to curve fitting makes it possible to resolve overlapped peaks in X-ray spectra that cannot be physically separated. The analytical results of both certified reference materials and industrial slag samples measured using the present technique are comparable to those of the same samples obtained by conventional fused disc measurements.

(cf. *ISIJ Int.*, **43** (2003), 1940)

Forming Processing and Thermomechanical Treatment

An integrated FE process model for the prediction of strip profile in flat rolling

T.H.KIM et al.

A full, finite element (FE)-based approach is presented for the precision analysis of the strip profile in flat rolling. Basic FE models for the analysis of the mechanical behavior of the strip and of the rolls are described in detail. Also described is an iterative strategy for a rigorous treatment of the mechanical contact occurring at the roll–strip interface and at the roll–roll interface. Then, presented is an integrated FE process model for the coupled analysis of the mechanical behavior of the strip, work roll, and backup roll in four-high mill. A series of process simulation are conducted and the results are compared with the measurements made in hot and cold rolling experiments.

(cf. *ISIJ Int.*, **43** (2003), 1947)

Roll force and torque prediction using neural network and finite element modelling

Y.Y.YANG et al.

Roll force and torque prediction play a critical role in modern rolling schedule control and optimisation. For a given steel grade, the roll force and torque will be determined by the stock temperature, mill reduction, roll speed, friction and heat transfer, *etc.* A finite element (FE) model is first developed for the modelling of the rolling process, and gives prediction of stock temperature, strain, strain rate, and stress profiles during rolling. The average roll force and torque were then calculated by post-processing based on the distribution of the local variables of strain, strain rate, temperature, *etc.* A series of rolling experiments has been conducted to validate the developed FE model before the FE model is then used to generate the training data for developing the neural network (NN) models. An important innovation here is the integration of orthogonal design techniques for training data generation at minimal computational cost with the help of a validated FE model. This effectively overcomes the difficulty of obtaining good training data with sufficient excitations and balanced distribution *via* data collection. Novel techniques have been adopted in the NN modelling, including structure optimisation and double-loop iterative training to achieve an accurate and robust NN model based on the existing process data. The resulting NN models are feasible for on-line control and optimisation of the rolling process, which is impossible for the FE model due to the heavy computation involved. Also, ensemble modelling techniques have been adopted to improve the model prediction, which can also give confidence bounds for the predictions. The developed NN models can be easily extended to cover different steel grades and stock sizes in a straight-forward way by generating the corresponding training data from an FE model.

(cf. *ISIJ Int.*, **43** (2003), 1957)

Experimental and numerical prediction of austenite grain size distribution in round-oval shape rolling

H.-C.KWON et al.

To determine austenite grain size (AGS) distribution during round-oval shape rolling of mild carbon steel (0.2 wt% C), three-dimensional non-isothermal finite element analysis in couple with an AGS evolution model available in the literature was carried out in the present investigation. A hot rolling test was conducted at the laboratory to verify the numerical data obtained from the analysis. For more accurate prediction of the temperature history during the process, interface heat transfer coefficient between the billet and rolls was determined by comparing the numerical temperature history with the measured data at three locations in the billet. Metallographic investigation of the rolled specimen after quenching showed that recrystallization behavior could be classified into two regions: interior zone with refined grain dominated by metadynamic recrystallization, and exterior zone with less refined grain due to static recrystallization. It was found that the numerically predicted AGS distribution was in good agreement with the experimentally measured one. In addition, the conventional additivity rule generally used for the prediction of recrystallization behavior for non-isothermal rolling conditions was modified in order to bear a better comparison with the experimentally measured AGS values.

(cf. *ISIJ Int.*, **43** (2003), 1967)

Welding and Joining

Numerical modeling of the transient liquid-phase diffusion bonding process of Al using Cu filler metal

Y.NATSUME et al.

A numerical modeling of dissolution and isothermal solidification during the transient liquid-phase (TLP) diffusion bonding process of Al using pure Cu filler metal based on a diffusion-controlled model was carried out. In the modeling, both the changes in volume accompanying interdiffusion between the base metal (Al) and the filler metal (Cu)

and the solid–liquid transformation were taken into account by using variable grids. The effect of a load applied to the base metal was also examined by considering simple force balance among the surface and interface energies of the base metal and liquid formed in the bonding region. The early dissolution process simulated by the developed model agreed with the experimental results, and the predicted isothermal solidification time of a sample with an applied load also agreed with the experimental results.

(cf. *ISIJ Int.*, **43** (2003), 1976)

Surface Treatment and Corrosion

Oxidation behavior of high-speed steels in dry and wet atmospheres

H.-H.KIM et al.

The oxidation behavior of high-speed steel (HSS), which is used as the work rolls in hot strip mills, was examined under both wet and dry oxidation conditions. In a dry atmosphere, carbides as well as the martensite matrix were oxidized, while only the matrix was oxidized in the wet atmosphere. After dry oxidation, the M_2C-, M_6C- and M_7C_3-type carbides maintained their original shapes, while the MC-type carbides were oxidized into parallelepiped (orthorhombic) crystals. The parallelepiped oxides were easily removed from the sample surface due to their low adhesion strength. Double-layered oxides were formed after oxidizing the matrix, in dry as well as wet atmospheres. The outer layer showed a dense structure after dry oxidation, while a columnar and porous layer was formed in the wet atmosphere. In the early stages of oxidation, the high-speed steels oxidized following the parabolic rate law in both the dry and wet atmospheres. The parabolic weight change transformed to a linear one, when the oxide thickness was $>1.3\,\mu$m by dry oxidation. The transition to a linear weight change was not observed in the wet oxidation. It is believed that, in a dry atmosphere, cracks occurred due to stress accumulation in the oxide layer, while the porous oxide layer hindered crack formation during wet oxidation.

(cf. *ISIJ Int.*, **43** (2003), 1983)

Transformations and Microstructures

Effect of initial solidified structure on ridging phenomenon and texture in type 430 ferritic stainless steel sheets

J.HAMADA et al.

This study investigated the effect of the initial solidified structure on the ridging phenomenon and the texture in type 430 ferritic stainless steel sheets that have $\alpha+\gamma$ two-phases at high temperature. The initial solidified structure with equiaxed or columnar grains was used and the effect of annealing of hot-rolled sheet on the texture formation during cold rolling and annealing was investigated. The effect of the initial solidified structure on the ridging phenomenon differed depending on annealing of hot-rolled sheet. With annealing of hot-rolled sheet, the columnar grain specimen exhibited severer ridging than the equiaxed grain specimen. On the other hand, without annealing of hot-rolled sheet, there was no effect of the initial solidified structure, and both specimens showed slight ridging. The columnar grain specimen with $\{001\}\langle uv0\rangle$ initial texture had strong $\{001\}\langle 110\rangle$ texture after hot rolling and annealing, and the grain colonies with $\{001\}\langle 110\rangle$ and $\{112\}\langle 110\rangle$ orientations were identified after cold rolling and annealing. However, without annealing of hot-rolled sheet, the equiaxed and columnar grain specimens showed roughly random textures. In the case without annealing of hot-rolled sheet, the deformation zone forming around the hard α' phase during cold rolling was effective for no influence of the initial solidified structure and the microstructure before cold rolling.

(cf. *ISIJ Int.*, **43** (2003), 1989)

Expressions for solubility products of Fe_3Nb_3C carbide and Fe_2Nb laves phase in niobium alloyed ferritic stainless steels

N.FUJITA et al.

Precipitation behaviors in niobium alloyed ferritic stainless steels, which are widely used as heat resistant materials in automotive exhausts, were investigated. The solubility products of Fe_3Nb_3C and Fe_2Nb, both of which are prominent precipitates in such steels, were experimentally obtained. The expressions of the solubility products with mass% are given by:

$$Fe_3Nb_3C;\ \log_{10}\{[Nb]^3[C]\} = -11\,613/T + 5.2178$$

$$Fe_2Nb;\ \log_{10}[Nb] = -3\,780.3/T + 2.4646$$

These were verified with some published experimental data. An attempt was also made to get thermodynamic parameters using the solubility products. The free energy changes for the precipitation reactions from niobium-supersaturated ferrite have been obtained. The expressions with mole fractions in ferrite matrix, *e.g.* $x_{Nb}^{\alpha\beta}$, are given by:

$$Fe_3Nb_3C\ (\beta);\ \Delta G^{\beta} = -222\,509 - RT\{6.423 + \ln(x_{Nb}^{\alpha\beta})^3(x_c^{\alpha\beta})\}$$

$$Fe_2Nb\ (\omega);\ \Delta G^{\omega} = -72\,334 - RT\{0.5469 + \ln x_{Nb}^{\alpha\omega}\}$$

(cf. *ISIJ Int.*, **43** (2003), 1999)

Effect of cooling rate after recrystallization on P and B segregation along grain boundary in IF steels

E.El-KASHIF et al.

Many researchers revealed that the addition of small amount of boron (B) significantly suppresses the intergranular fracture (IGF) induced by segregated phosphorous (P) along grain boundaries in iron and steels. However the details of this suppression have not been clarified yet. In the present study, the behavior of B and P during heat treatment and the mechanism of toughening caused by B in interstitial free (IF) steels containing P was examined using alpha-particle track etching (ATE), tensile testing, Auger electron spectroscopy (AES) and scanning electron microscopy (SEM). The results of ATE exhibit that the degree of grain boundary segregation of B depends on the cooling rate from 850°C and shows maximum at about 10°C/s for high B–low P steel while it shows maximum at about 555°C/s for high B–high P steel. The results of ATE also reveal that low P steel shows higher B segregation than high P steel at all cooling rates, while the difference is reduced by increasing the cooling rate. It was found that elongation at low temperatures is improved when B segregates along grain boundaries. The results of AES indicate that the grain boundary segregation of B markedly decreases the segregation of P and consequently the elongation is enhanced. Therefore, controlling of the cooling rate after recrystallization decreases the brittleness caused by P in IF steel. Segregation of B and P after heat treatment can be explained by a duplex equilibrium and non-equilibrium mechanism before and during cooling.

(cf. *ISIJ Int.*, **43** (2003), 2007)

Effect of equalisation time on the austenite grain size of simulated thin slab direct charged (TSDC) vanadium microalloyed steels

J.ZHANG et al.

The thin slab direct charging process (TSDC) as applied to microalloyed steels has had a considerable development due to its relatively low production costs and ability to produce steels with good mechanical and toughness properties, comparable to those manufactured by the conventional cold charging process (CCC). This research is concerned with the effect of equalisation time on the microstructures.

Three equalisation times (53 min, 318 min, and 1 333 min) at 1 150°C were investigated for a vanadium microalloyed steel, which contained a low carbon content (0.073 wt%) and a high nitrogen content (0.021 wt%). The experimental results show that MnS precipitates provided the main pinning forces during casting due to the high solubility temperature, but MnS particles did not provide a sufficient pinning force to prevent the austenite grains from growing. The austenite grain growth appears more likely to be abnormal in this stage. AlN precipitates were only identified at the longest equalisation time due to a low precipitation rate. The AlN pinning effect was evident at 1 333 min equalisation time, and was able to prevent further austenite grain growth by providing an additional pinning force. The study shows that vanadium does not have any effect on austenite grain growth at 1 150°C because of its low solubility temperature in austenite. When the steel was water-quenched, vanadium remained supersaturated in the solution but tempering in the ferrite phase field (650°C) can promote VN or VCN precipitation often using AlN as the nuclei.

(cf. *ISIJ Int.*, **43** (2003), 2015)

Application of grain boundary engineering in lead-free "green steel"

C.I.GARCIA et al.

The development of a non-leaded free-machining steel has used atom probe tomography to measure the concentration of tin atoms at the ferrite grain boundaries. Comparing to lead-containing 12L14 and 1215 steels, 12T14 has proven to be equal or su-

perior in terms of machinability. Atom probe analysis has revealed that grain boundary segregation of tin is responsible for the improved machinability performance.

(cf. *ISIJ Int.*, **43** (2003), 2023)

Multiphase crystallography in the nucleation of intragranular ferrite on MnS+V(C, N) complex precipitate in austenite

T.FURUHARA et al.

Crystallographic orientation relationships between intragranular ferrites, the MnS+V(C, N) complex precipitates acting as ferrite nucleation sites, and austenite matrix were studied in Fe–Mn–C alloys by scanning electron and transmission electron microscopy. VC holds a cube–cube orientation relationship ($\langle 001\rangle_\gamma // \langle 001\rangle_{VC}$) when it is formed directly within austenite grains in an Fe–12Mn–0.8C–0.3V alloy. When VC precipitates nucleate on incoherent MnS particles dispersed in austenite, there is no specific orientation relationship between the three phases. Intragranular ferrite idiomorphs nucleating on the MnS+V(C, N) complex precipitate in austenite in Fe–1.5Mn–0.2C and Fe–2Mn–0.2C alloys often hold the Baker–Nutting orientation relationship ($(001)_\alpha // (001)_{V(C,N)}$, $[110]_\alpha // [100]_{V(C,N)}$). Although several irrational ferrite/V(C, N) orientation relationships were observed, misorientation for either low-index planes or directions are relatively small between ferrite and V(C, N) for those relationships. The orientation relationships between intragranular ferrite and austenite were estimated by examining the misorientations between the ferrite and the neighboring martensite lathes from the Kurdjumov–Sachs inter-variant relationships. There is no specific orientation relationship between the intragranular ferrite idiomorph and the austenite matrix because of the low-energy orientation relationships between ferrite and V(C, N).

(cf. *ISIJ Int.*, **43** (2003), 2028)

Mechanical Properties

Production and properties of nano-scale oxide dispersion strengthened (ODS) 9Cr martensitic steel claddings

S.UKAI et al.

The 9Cr–ODS martensitic steel claddings were developed by cold-rolling and subsequent heat-treatment. The standard chemical composition is Fe–0.13C–9Cr–2W–0.2Ti–0.35Y_2O_3. The substantially elongated grains formed by cold-rolling turned out to be into equi-axied grains by ferrite to austenite phase transformation at the final heat-treatment. The produced claddings have the tempered martensitic structure and excess oxygen of 0.060 mass%. The superior tensile and creep rupture strength were shown in the produced cladding, compared with conventional ferritic (PNC–FMS) and even austenitic (PNC316) claddings at higher temperature and extended time. The strength improvement is attributed to finely distributed nano-scale complex oxide. The coarser ferrite grains produced by slow cooling make further improvement in the tensile and creep rupture strength beyond those of tempered martensite at high temperature and longer testing time. The higher excess oxygen content of 0.137 mass% prevents fine distribution of the oxide particles that lead to inferior high temperature tensile and creep strength.

(cf. *ISIJ Int.*, **43** (2003), 2038)

Mechanical properties of welded joints of 780 MPa grade ultra-fine grained steels

H.QIU et al.

Three kinds of 780 MPa grade ultra-fine grained steels with different chemical composition were produced by warm rolling. The steels were characterized by ultra-fine ferrite grains (less than 1 μm). With the steels strength-overmatching welded joints were prepared, and their mechanical properties were investigated. It is found that softening occurred in the heat-affected zone (HAZ) because of the coarsening of ferrite grains due to welding heat input. However, by using low welding heat input and strength-overmatching weld metal, the detrimental effect of softening on strength was restrained, and welded joints with strength equivalent to that of base metal were obtained. The deformability of welded joints was found to be related to the yield ratio (yield strength / tensile strength) of base metal. Low yield ratio is desirable to the deformability of welded joints. The HAZs in the welded joints of low welding heat input of 10 kJ/cm have good impact toughness for all the steels. Except for 0.14C–0.30Si–1.46Mn steel, the HAZs in the welded joints formed from the other two steels also have good impact toughness for welding heat input of 20 kJ/cm, and their fracture appearance transition temperature (vTrs) of the HAZs is lower than −40°C, and their Charpy impact energy at −40°C exceeds 200 J.

(cf. *ISIJ Int.*, **43** (2003), 2046)

Grain boundary damage evolution and rupture life of service-exposed 1.25Cr–0.5Mo steel welds

S.FUJIBAYASHI

For components operated under creep regime, Type IV cracking would be the most likely failure mode if they were fabricated from ferritic steels. In the present work, creep behavior of 1.25Cr–0.5Mo steel weldment operated at 500°C for 28 years has been examined. The morphology of grain boundary damage was observed to clear the cause of Type IV cracking. Intergranular failure at the Intercritical HAZ took place in spite of short testing duration, which was less than 1 000 h. Change in feature of damage was observed with time to rupture. The number of cavities and the area of cavitated at failure increased as time to rupture became longer. Specimens broken with short duration showed few cavities resolvable by optical microscopy adjacent to the final intergranular crack path. On the other hand, more profuse cavitation in terms of number and area was observed in the specimens tested for 1 000 h and longer. However, commonly observable feature in both short and long term specimens was preferential damage occurrence at the triple points, proving that Type IV damage was caused by grain boundary sliding. The change in failure location in laboratory tests, where parent material failure often occurs due to too much acceleration, can be explained by relatively low stress exponent and activation energy associated with grain boundary sliding. Therefore, life assessment by conventionally employed Time–Temperature Parameter such as Larson–Miller Parameter could result in non-conservative estimation since equivalent *LMP* at failure would be smaller with increase in time to rupture.

(cf. *ISIJ Int.*, **43** (2003), 2054)

High temperature mechanical behavior of a 30%Ni–19%Cr steel

J.A.JIMENEZ et al.

The deformation behavior at high temperature of a Type 800 Incoloy alloy reinforced by TiC particles was investigated by tensile and torsion tests at temperatures ranging from 800 to 1 200°C. The as-received material exhibited a microstructure of coarse equiaxic grains with subgrains decorated by small TiC particles. The material showed an activation energy for plastic flow of 400 kJ/mol similar to the activation energy for lattice diffusion in austenitic stainless steels. The stress exponents varied strongly with testing conditions. After testing at temperatures up to 1 000°C, the initial austenitic grains were elongated in the tensile direction, but the subgrain structure did not change with stress. In contrast, a microstructural refinement was observed after tensile testing at 1 100°C, which was associated with a process of dynamic recrystallization that occurs during deformation. At this temperature the deformation behavior of the material can be described by a slip creep mechanism. At the rest of the test temperatures the controlling mechanism is that of constant-structure slip creep.

(cf. *ISIJ Int.*, **43** (2003), 2062)