（＊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

Relationship between the aluminum and oxygen and sulfur partitions for molten iron and a $CaO–Al_2O_3–ZrO_2$ slag in equilibrium

J.TANABE et al.

The relationship between the aluminum–oxygen and sulfur distribution ratio for molten iron and a $CaO–Al_2O_3–ZrO_2$ slag in equilibrium at 1 873 K was studied using an Al_2O_3 or CaO-stabilized ZrO_2 crucible. The slag and molten iron equilibrated with $CaO·2Al_2O_3$ and Css (cubic solid solution in $CaO–ZrO_2$ system) in the Al_2O_3 crucible, and with $CaO·ZrO_2$ and Css in the ZrO_2 crucible. These equilibrium states coincided with the phase diagram of $CaO–Al_2O_3–ZrO_2$. From the concentrations of aluminum and oxygen dissolved in molten iron, the Al_2O_3 activity in the slag was determined to be 0.393 in the Al_2O_3 crucible and 0.385 in the ZrO_2 crucible. These activities were compared with the data in the $CaO–Al_2O_3$ and $CaO–ZrO_2$ systems. The sulfur distribution ratio was higher a little in the ZrO_2 crucible than in the Al_2O_3 crucible and increased with aluminum content. The sulfide capacity of the fluxes was determined to be 8.77×10^{-5} and 9.10×10^{-5} in the Al_2O_3 and ZrO_2 crucibles, respectively.

(cf. *ISIJ Int.*, **46** (2006), 169)

Phosphorous partition between $2CaO·SiO_2$ particles and $CaO–SiO_2–Fe_tO$ slags

R.INOUE et al.

The behavior of phosphorous transfer from P_2O_5-containing $CaO–SiO_2–Fe_tO$ slags to $2CaO·SiO_2$ particles homogeneously dispersed in slag has been studied by using a microprobe analysis. The maximum phosphorus distribution ratio between $2CaO·SiO_2$ particle and slag is obtained at the nose composition of $2CaO·SiO_2$ primary phase region in $CaO–SiO_2–Fe_tO$ phase diagram and the temperature dependence of this distribution ratio is small. The phosphorous transfer rate from slag to a $2CaO·SiO_2$ particle with 20 to 50 μm is considerably fast and a $2CaO·SiO_2$ particle changes to the particle with the composition of $2CaO·SiO_2–3CaO·P_2O_5$ solid solution within 5 s. In the case of particles present in cluster, only the rim part (5 μm) of a particle changes to the composition of $2CaO·SiO_2–3CaO·P_2O_5$ solid solution within 5 s, but small size particles with 3 to 8 μm completely change to the particles with the composition of $2CaO·SiO_2–3CaO·P_2O_5$ solid solution within 5 s.

(cf. *ISIJ Int.*, **46** (2006), 174)

Behavior of phosphorous transfer from $CaO–Fe_tO–P_2O_5(–SiO_2)$ sag to CaO particles

H.SUITO et al.

Lime particles (0.5 to 1 mm) were added by dropping to $CaO–Fe_tO–P_2O_5$ slag at 1 400°C, followed by stirring and the reaction products near a CaO particle/slag interface were determined by a microprobe analysis (EPMA-EDX). The $3CaO·P_2O_5$ and $4CaO·P_2O_5$ phases were crystallized depending on the amount of added CaO particles which are rapidly dissolved after the contact with a molten slag. The phosphorous distribution ratios between calcium phosphates and $CaO–Fe_tO$ slag obtained at temperatures between 1 400 and 1 570°C are higher than those between $2CaO·SiO_2–3CaO·P_2O_5$ solid solution and $CaO–SiO_2–Fe_tO$ slag. Lime particles (0.3 to 0.5 mm) are added to $CaO–SiO_2–Fe_tO–P_2O_5$ slag at 1 400°C and the reaction products near a CaO particle/slag interface are determined by EPMA-EDX. The $2CaO·SiO_2–3CaO·P_2O_5$ solid solution layer is formed on the surface of a CaO particle and thereafter the $CaO–Fe_tO$ slag layer is formed between a CaO particle and $2CaO·SiO_2–3CaO·P_2O_5$ solid solution layer which is surrounded by $CaO–SiO_2–Fe_tO–P_2O_5$ slag. It is also experimentally confirmed that the meso-phase slag refining is superior to conventional slag refining and the discrepancy between the theoretical and experimental results obtained by the meso-phase slag refining is discussed.

(cf. *ISIJ Int.*, **46** (2006), 180)

Mechanism of dephosphorization with $CaO–SiO_2–Fe_tO$ slags containing mesoscopic scale $2CaO·SiO_2$ particles

R.INOUE et al.

Dephosphorization of a liquid Fe–5mass%P alloy with a solid–liquid coexisting flux in which $2CaO·SiO_2$ particles (20 to 50 μm) are uniformly dispersed in $CaO–SiO_2–Fe_tO$ slags has been studied at 1 400°C. For the slag with high SiO_2 and low T.Fe contents, the change of slag composition is small and the fraction of $2CaO·SiO_2$ particles to slag increases slightly during dephosphorization in which the $L_P^{solid/slag}$ and $L_P^{slag/metal}$ values are low. For the slag with moderate SiO_2 and high T.Fe contents, the change of slag composition is considerable and the fraction of $2CaO·SiO_2$ particles to slag increases considerably during dephosphorization in which the $L_P^{solid/slag}$ and $L_P^{slag/metal}$ values are high at initial period, but these values decrease with time. For the slag with low SiO_2 and high T.Fe contents, the change of slag composition is small and the fraction of $2CaO·SiO_2$ particles to slag decreases slightly during dephosphorization in which the $L_P^{slag/metal}$ and $L_P^{solid/slag}$ values are high, but $L_P^{solid/slag}$ value decreases considerably even with small change of slag composition.

(cf. *ISIJ Int.*, **46** (2006), 188)

Ironmaking

Comparison of blast furnace raceway size with theory

G.S.GUPTA et al.

A previously developed one-dimensional mathematical model, to explain raceway hysteresis, is used to predict the raceway diameter in operating blast furnaces and hot models. Raceway size obtained from the open literature under various conditions for various blast furnaces are compared with computed predictions. In addition the predictions are also compared with published outcomes from other hot models. Simulated results on raceway diameter are in very good agreement with published operating blast furnace and hot model data. The effect of various parameters such as tuyere and hearth diameter, coke size and density, void fraction and bed height on raceway diameter has been studied.

(cf. *ISIJ Int.*, **46** (2006), 195)

Steelmaking

In situ observation of aluminothermic reduction of MgO with high temperature optical microscope

J.YANG et al.

Desulfurization and deoxidation of molten iron with magnesium vapor produced *in-situ* by aluminothermic reduction of magnesium oxide has been developed. In the present study, the mechanism of aluminothermic reduction of magnesium oxide by use of pellets composed of magnesium oxide and aluminum powders was discussed. SEM observation of the pellets at different reduction stages for various temperatures showed that fracture and disappearance of the alumina films on the aluminum particles were stimulated above 1 473 K, and thus the reduction of magnesium oxide was greatly accelerated.

From *in-situ* observation of the aluminothermic reduction of magnesium oxide using a high temperature optical microscope (HTOM), it was found that the reduction proceeded after the penetration of molten aluminum into the magnesium oxide phase. The penetration began at 1 273 K and it was accelerated above 1 373 K. The reduction took place violently at 1 473 K. SEM observation and EDS analysis of the cooled sample revealed that the penetration took place only through cracks of the alumina film.

In-situ observation of the melting process of aluminum particles together with SEM observation of the cooled sample showed that the thermal stress and the stress formed during phase transformation could break up the alumina film and the outflow of molten aluminum did take place at the elevated temperature.

(cf. *ISIJ Int.*, **46** (2006), 202)

Casting and Solidification

Experimental simulation and mathematical modeling of air bubble movement in slab caster mold

V.SINGH et al.

Experimental simulation of air bubble movement in a 1/3rd scale model slab caster mold has been done for parallel, upward and downward port submerged entry nozzle (SEN) with different water flow and air flow rates in order to study the bubble penetration depth, horizontal dispersion and the air jet angle. It has been observed that the bubble penetration depth depends more on the flow rate of water rather than that of air. The bubble penetration depth also depends on the port angle and on the "well" provided on the SEN. Below a certain critical water flow rate the flow becomes asymmetric in the slab caster mold for a given flow rate of air. SEN with a well depth may help to avoid bubble entrapment defects in the slab at the cost of higher surface disturbances on the mold. A mathematical modeling of the air bubble movement in water was also carried

out for the same experimental set up where it was observed that for same air flow rate the bubble penetration depth was more for higher water flow rate confirming to the experimental findings. The experience gained from the experiment and mathematical modeling helped to fine tune the parameters at the caster so that the strike rate of ultra low carbon grade steel could be improved substantially.

(cf. *ISIJ Int.*, **46** (2006), 210)

Use of a multi-sensor technique to monitor the mould oscillation in a continuous billet caster

P.P.SAHOO et al.

Producing a defect free product is most important in the process of continuous casting as the defect may propagate to the end product and also can increase the downgrading. Inadequate oscillation parameters as well as a defective oscillation may greatly affect the surface quality of the cast product. So monitoring friction along with the oscillation profile of the oscillator can lead to take corrective action when there is an increase in friction between the mould and strand or if there is any wear and tear in the machine components. In the present work a multi-sensor based mould oscillation monitoring system was developed to monitor the mould health as well as the friction between the mould and strand of a billet caster. Friction force was calculated for different carbon composition, type of lubrications and was co-related with the surface quality of billets. Also monitoring the mould health was able to detect problems in the machine and corrective action could be taken care of in time.

(cf. *ISIJ Int.*, **46** (2006), 219)

Infiltration phenomena of molten powder in continuous casting derived from analysis using reynolds equation Part 1: Steady analysis

K.OKAZAWA et al.

A new type of model for powder infiltration in the continuous casting process of steel is introduced. In the model, Reynolds equation is used as a fundamental equation and the distance between a mold and a cast metal is supposed to be variable.

It is clarified that when the gap between the mold and the cast metal widens downward, many behaviors about the powder infiltration can be explained with using the model. Therefore, it is presumed that the shape of the mold/cast metal gap being wider downward is important to the powder infiltration. From the stationary analysis in this shape of the gap, it is obtained that without the mold oscillation the gap between the mold and the cast metal closes, which means that casting is impossible unless the mold oscillates. Furthermore it is obtained that although the gap closes during the mold descending, the gap opens during the mold ascending. However the powder infiltration does not occur because the powder also ascends as the mold ascends.

From the above, it is presumed that the powder infiltration is unsteady phenomena. In the following report, the powder infiltration phenomena are analyzed with an unsteady model.

(cf. *ISIJ Int.*, **46** (2006), 226)

Infiltration phenomena of molten powder in continuous casting derived from analysis using reynolds equation Part 2: Unsteady analysis

K.OKAZAWA et al.

A new type of model for the powder infiltration in continuous casting of steel is developed. Succeeding the previous report on a steady state analysis, this paper presents an unsteady model that uses Reynolds equation and the equation of the motion of the solidified shell as fundamental equations.

The analysis clarifies in details the cyclic movement of a solidified shell during mold oscillation. Mold powder can be infiltrated because the cyclic movement of the shell lags behind the mold oscillation. This provides a period when the mold/cast metal gap opens, during the downward motion of the mold. In this period, molten powder is infiltrated down into the channel. The model also clarifies that the powder infiltration is greatly influenced by two factors; the peak distance between solidified shell and mold wall during the oscillation, and the phase shift of the movement of solidified shell from the mold oscillation. Furthermore, the tendency of the powder consumption to decrease with increasing the powder viscosity can be easily understood through the mechanism of the powder infiltration derived from the analysis.

Those results indicate that the model essentially reveals the unsteady behavior of powder infiltration during the mold oscillation.

(cf. *ISIJ Int.*, **46** (2006), 234)

Numerical simulation of microstructure of Al–Si/SiC_p composites during stir casting process with particle pushing model

B.LI et al.

Particle distribution has vital influence on the microstructure and the final performance of particle reinforced metal matrix composite. The formation of microstructure of SiC particle reinforced Al–7.0mass%Si composite made by stir casting was simulated in this paper. Two-dimensional models under normal solidification condition including macro heat transfer, micro nucleation, equiaxed dendrite growth and particle pushing were presented. Two sets of meshes were used to carry out macro and micro calculation, respectively. A modified cellular automaton method coupled with finite difference method was used to simulate the evolution of the composite microstructure. In addition, the effects of SiC particle volume fraction, different casting processes, pouring temperature and cooling rate on the composite microstructure and the particles distribution were analyzed. The simulated results can clearly show the particle clustering/accumulation phenomenon caused by particle pushing. The calculated cooling curve and final predicted microstructure are in good agreement with the experimental results. Grain size is smaller for metal mould casting than sand mould casting. With the increase of SiC particle volume fraction or cooling rate, the grains of the matrix alloy are refined and particle are distributed more uniformly. As the pouring temperature increases, particles are distributed more uniformly.

(cf. *ISIJ Int.*, **46** (2006), 241)

Cold model experiment on infiltration of mould flux in continuous casting of steel: Simple analysis neglecting mould oscillation

T.KAJITANI et al.

A new cold model of continuous casting is developed to clarify the infiltration of mould flux into channel between a mould and a solidifying shell. In the experiment, silicone oil is poured and infiltrated down into the channel between an acrylic plate and a moving belt. In contrast with most of the previous analyses that assumed a fixed thickness of the liquid flux film, this model is based on an idea that the thickness can be varied depending on the balance of forces acting on the shell: static pressure in the molten steel pool, and dynamic and static pressure in the mould flux channel. Furthermore, a linear gauge sensor that is in contact with the acrylic plate monitors the film thickness of oil, while in continuous casting the thickness of mould flux cannot be measured during the operation.

Simple experiments without oscillating motion clearly reveal that the infiltration behavior is largely dependent on the profile of channel: In the channel that becomes narrower in downward direction, the infiltration of oil is enhanced with the increase of both belt velocity and oil viscosity. In contrast, for the channel that becomes wider along the downward direction, the increase of the velocity and the viscosity reduces the oil infiltration.

In continuous casting operation, the increase of both casting velocity and viscosity of mould flux decreases the mould flux consumption. Those observations indicate that the infiltration of mould flux is strongly governed by the channel that becomes wider in casting direction.

(cf. *ISIJ Int.*, **46** (2006), 250)

Water model and CFD studies of bubble dispersion and inclusions removal in continuous casting mold of steel

Y.KWON et al.

A water model study was undertaken to investigate bubble dispersion and inclusions removal by bubble adhesion in continuous casting mold. The water flow rate was varied in the range of 37–74 L/min, which is equivalent to 1.0–2.0 m/min of the casting speed in continuous casting process. The gas flow rate was varied in the range of 0–2.5 L/min. Silver coated hollow glass beads (SCHG) and plastic particles were used to imitate the inclusions and to investigate the effect of wettability, *i.e.*, contact angle of the inclusions with liquid, on inclusion removal by bubble adhesion. Effect of gas and water flow rates on bubble dispersion in the mold was systematically determined. Inclusion removal at different gas and water flow rates was quantitatively determined. It was identified that the wettability of inclusions with liquid was a decisive factor in inclusion removal: with low wettability, *i.e.*, high contact angle, removal efficiency increased with increasing gas and liquid flow rates, whereas removal efficiency was hardly affected by gas flow rate with high wettability, *i.e.*, low contact angle.

To interpret the results of the water model experiments, various computational fluid dynamics (CFD)

models which had been reported were applied. None of them was able to represent the experimental results within an acceptable discrepancy. Two new CFD models, which employed a modified Reynolds number and force field theory around the bubble, were developed to simulate bubble dispersion and inclusion removal, respectively.

The results indicated that these models could simulate bubbles dispersion and inclusion removal and showed reasonable agreement with results of water model in continuous casting mold.

(cf. *ISIJ Int.*, **46** (2006), 257)

Welding and Joining

Integrating finite element based heat transfer analysis with multivariate optimization for efficient weld pool modeling

A.TRIVEDI et al.

Measurement of weld thermal cycle and peak temperature is a difficult task in fusion welding due to high peak temperature and rapid thermal cycle. Numerical modeling of heat transfer process in fusion welding provides a useful tool for the prediction of the weld pool shape and thermal cycles. However, the reliability of the predictions greatly depends on the accuracy of the input parameters provided to such models. In the case of laser beam welding, the absorptivity represents an important variable that defines the actual heat input for a given power while the value of absorptivity rarely known *a-priori* with confidence. The present work provides a novel framework where the unknown value of the absorptivity is obtained using an inverse approach by integrating finite element based heat transfer simulation and multivariate optimization procedure. The heat transfer simulation predicts the weld pool dimensions for known welding conditions and assigned values of absorptivity. The optimization algorithm tracks the error in the prediction, its sensitivity with small change in absorptivity, and finally yields the optimum value of absorptivity iteratively. Eight known welding conditions and corresponding weld pool measurements were utilized in this work. It is experienced that the optimum value of absorptivity remains nearly same irrespective of the number of known measurements used for the optimization process thereby indicating the robustness of the inverse approach.

(cf. *ISIJ Int.*, **46** (2006), 267)

Marangoni convection and gas tungsten arc weld shape variations on pure iron plates

S.LU et al.

Bead-on-plate welds are made on pure iron using Ar–O_2 mixed shielding gas in TIG welding with the O_2 content in the shielding from 0.1 to 3.0%. The weld shapes are analyzed by optical microscopy and the weld metal oxygen content was measured using an oxygen/nitrogen analyzer. Results showed that the weld shape is sensitive to the concentration of the shielding gas. When the O_2 content in the shielding gas is in the range of 0.3 to 1.0%, the weld shape is narrow and deep and the weld depth/width ratio reached 0.5. Outside this range, the weld shape is shallow and wide. The small addition of oxygen to the argon shielding gas in TIG welding provides a means of adjusting the oxygen content in the liquid pool. The oxygen in the pure iron pool plays an important role as an active element, which directly affects the Marangoni convection mode in the pool. When the oxygen content in the pure iron pool is between 80 ppm and 250 ppm, an inward Marangoni convection occurs on the pool surface. The weld beads were significantly oxidized with the increasing oxygen content in the shielding gas. However, this oxide layer will not become a barrier for oxygen absorption into the liquid pool.

(cf. *ISIJ Int.*, **46** (2006), 276)

Surface Treatment and Corrosion

Fluoride speciation in stainless steel pickling liquor

J.L.GÁLVEZ et al.

Mixtures of hydrofluoric and nitric acids are used in the pickling of stainless steels, in order to remove oxide scale, generating pickling waste liquors with high HF concentration. Species appearing in this mixed acid solution are fluoride-metal complexes with high stabilization constants. This work discusses about the modelling of equilibrium reactions that could take place, like complexation of iron and chromium. As observed in the literature, 31 species could be present in pickling liquor with 25 equilibrium reactions. Activity coefficients are calculated using Bromley's methodology that depends on cation–anion interaction parameter B. New parameters at 25°C have been calculated, using Nelder and Mead Simplex Algorithm. The new model shows that FeF_3, CrF^{2+} and Ni^{2+} are the main metallic forms in the solution and undissociated hydrofluoric acid has a high relative concentration, while free fluoride practically does not exist in solution. In neutralization processes, free fluoride is released from undisocciated hydrofluoric acid. Therefore, high fluoride complexes are formed, which could precipitate instead of metal hydroxides.

(cf. *ISIJ Int.*, **46** (2006), 281)

Tribological behavior of microarc oxidation coatings on aluminum alloy

W.XUE et al.

Thick ceramic coatings were fabricated by microarc oxidation on 2024 aluminum alloy in a silicate solution. The phase composition and microhardness in the coatings were determined. The unlubricated tribological performance of the coatings was investigated using a SRV ball-on-disc friction and wear test system with reciprocating motion against sintered WC ball. The typical worn surfaces of the Al substrate and the ceramic coatings were observed by a scanning electron microscope. Under the same wear condition, the wear rates in different depth coatings are nearly similar. However, in a same depth of the coatings, wear rate gradually decreases with wear duration, and the lowest wear rate is less than 3.29×10^{-7} mm^3/N m. During friction process, a WC transfer layer was formed on the tribo-contact area of the coatings, which takes advantage of decreasing the wear rate. The friction coefficient in a steady friction stage is about 0.52. After the Al alloy is treated by microarc oxidation, its wear resistance is improved over three orders of magnitude. The high wear resistance of the microarc oxidation coatings results from a nearly perfect distribution of α-Al_2O_3 and γ-Al_2O_3 phases in the coating.

(cf. *ISIJ Int.*, **46** (2006), 287)

Transformations and Microstructures

Alloy design and property evaluation of new β type titanium alloy with excellent cold workability and biocompatibility

K.TANEICHI et al.

Alloy designing of new β type titanium alloy with excellent cold workability and biocompatibility was conducted by using total heat numbers of 38 titanium alloys containing Nb, Fe, Ta or Zr in basic compositions of Ti–10%Mo–2%Fe and Ti–14%Mo. Cold workability was evaluated based on hardness values obtained by solution treating and after cold rolling with a rolling reduction ratio up to 90% as well as a critical rolling reduction ratio for onset of cracking. Excellent cold workability in β type titanium alloy was obtained by enhanced thermal and mechanical stability of β phase through optimum addition of β stabilizing elements in Ti–14%Mo base alloy and a reduction of β transus below 1 000 K. Newly developed alloy of Ti–14%Mo–3%Nb–1.5%Zr yields Vickers hardness values of 240 and 284 in as solution treating and after a cold rolling reduction ratio of 90%, respectively, and no cracking occurs in rolling reduction ratio up to 90%. New titanium alloy shows the almost similar level of non-toxicity to other implant titanium materials in the cell culture test using L929 cells, although a slightly increased passive current density is observed by anodic polarization test in both solutions of saline and 1 mass% lactic acid. New austenitic stainless steel of Fe–6%Mn–22%Cr–10%Ni–2%Mo–0.4%N used as one of comparative materials for evaluation of biocompatibility results in the same level of non-toxicity with new titanium alloy, while relatively poor non-toxicity of the Type 316L steel is observed by cell culture test.

(cf. *ISIJ Int.*, **46** (2006), 292)

Microstructure and texture changes in a low-alloyed TRIP-aided steel induced by small plastic deformation

A.WASILKOWSKA et al.

The microstructures and the textures of TRIP-assisted and Dual Phase steel in undeformed state and after 10% strain applied parallel to the rolling direction of the steel sheet were studied by optical microscopy, EBSD, TEM and XRD.

It was found that the strain-induced transformation of retained austenite to martensite leads to localized deformation of ferrite close to the ferrite/martensite phase boundaries and the formation of a composite skeleton of several phases (bainite, retained austenite and martensite), clasping the ferrite grains, which thereby decrease in size. Ferrite and

retained austenite deform simultaneously to minimize the local stresses at the phase boundaries, until the strain-induced martensitic transformation takes place. The composite-like strengthening behaviour in a TRIP-aided steel might be expressed by the decreasing free path of dislocations in ferrite due to the enlarging and thickening of the multiphase skeleton as plastic deformation progresses, without changing significantly the main texture components in the material.

(cf. *ISIJ Int.*, **46** (2006), 302)

Carbide dispersion carburizing (CDC) of Fe–Mo–V based high-speed steels

I.OHNUMA et al.

The carbide dispersion carburizing process was applied to Fe-based high-speed steels, which contained multiple carbide-forming elements, Mo and V. Fine carbides precipitated during the carburization and the dispersed particles in the Fe–Mo–V–C alloys heat-treated at 1 200°C were identified as VC, $(Mo, V)_2C$, and $(Fe, Mo)_6C$, which behave as effective inhibitors against the grain growth of austenite and as reinforcers resulting in increased hardness of the martensitic matrix. The maximum Vickers hardness of the Fe–10Mo–5V–2.05C alloy quenched from 1 200°C and tempered at 600°C achieved values of 1 100 and 1 000, respectively. Thermodynamic calculation of the Fe–Mo–V–C quaternary system proved to be useful for optimizing the composition of carbide forming elements, the carburizing conditions, and the microstructure of carburized and solution-treated alloys.

(cf. *ISIJ Int.*, **46** (2006), 310)

Strain-induced transformation behaviour of retained austenite and tensile properties of TRIP-aided steels with different matrix microstructure

M.MUKHERJEE et al.

The effects of strain rate and temperature on the strain induced transformation behaviour of retained austenite and hence mechanical properties of TRIP-aided steels with annealed martensite (AM), bainitic ferrite (BF) and polygonal ferrite (PF) matrix microstructures were examined. For this, tensile tests were carried out at four different strain rates varying from $3.33\times10^{-5}s^{-1}$ to $3.33\times10^{-2}s^{-1}$ at room temperature and at 150°C. Additional intermittent tests were carried out at intermediate strain rates to estimate the extent of strain induced transformation of austenite to martensite using X-ray diffraction analysis. Tensile strength (TS) decreased with strain rate at both temperatures, though the TS at 150°C was lower for all steels except for BF steel tested at $3.33\times10^{-5}s^{-1}$. The total elongation (TEL) for PF steel significantly improved at 150°C at all strain rates, with a maximum of 78% obtained at $3.33\times10^{-3}s^{-1}$, the corresponding TS being 930 MPa. A similar effect was seen in AM steels tested at $3.33\times10^{-3}s^{-1}$ and $3.33\times10^{-4}s^{-1}$. However, in BF steel, higher temperature had a detrimental effect on TEL, especially at strain rates of $3.33\times10^{-2}s^{-1}$ and $3.33\times10^{-3}s^{-1}$.

(cf. *ISIJ Int.*, **46** (2006), 316)

Mechanical Properties

Hardness based creep life prediction for 2.25Cr–1Mo superheater tubes in a boiler

S.FUJIBAYASHI et al.

In the present work, the applicability and limitation of a hardness based approach to evaluate creep strength of boiler tubes fabricated from 2.25Cr–1Mo steel have been examined. For superheater tubes in a boiler, a screening technique to judge the damage level would be useful since the number of tubes to be assessed is numerous. It was confirmed that creep strength of tube materials was well correlated with hardness independently of service histories. However, the obtained relationship should not be extended to hardened materials associated with higher dislocation densities. It was found that cold work prior to creep tests remarkably decreased rupture lives despite high hardness values. The extent of change in precipitates, in terms of carbides spherodization and growth of PFZ, was more pronounced in a pre-strained material, presumably due to contribution of pipe diffusion. A similar tendency is also observable in quenched and tempered 2.25Cr–1Mo plate materials, in which densely populated dislocations were introduced at fabrication. For the critical judgement, a more straightforward method, for example examining the removed tubes in service in an iso-stress manner, should be employed. However, time consuming and expensive tests do not necessarily generate reliable answers. Since a test piece machined from an actual boiler tube inevitably has got a small cross-sectional area, rupture life in air is significantly reduced by oxidation. The metal loss, which is a function of temperature and testing duration, can be larger in a test at low temperature rather than that in a short-term test at high temperature. Metal loss at failure for an iso-stress tested specimen can be reduced with increase in testing temperature, suggesting that a creep test under accelerating temperature can derive more realistic prediction.

To evaluate the genuine creep strength, the rupture lives in NIMS database obtained in air were converted into those in vacuum using the damage mechanics by Kachnov and Rabotnov. The following equation was obtained to predict the rupture life in vacuum on the basis of hardness measurement prior to service.

Larson Miller Parameter (LMP)

$$=(\log t_{rv}+20)T$$
$$=18\,858-6\,183\log(\sigma/H_{vo})-1\,807\log^2(\sigma/H_{vo})$$

where t_{rv} is the rupture life in vacuum, T is the temperature in Kelvin and H_{vo} is the Vickers hardness.

(cf. *ISIJ Int.*, **46** (2006), 325)

New Materials and Processes

Effect of pressure on the behavior of cathode spots in oxide removal by arc discharge

K.TAKEDA et al.

The effects of pressure on the cleaning action of the cathode spots were investigated in a wide pressure range from 10 to 20 000 Pa of inert atmosphere.

Experiments were carried out by using hot rolled steel plates, the surfaces of which were covered with thick oxide of 5–10 μm.

Experimental observation revealed the following results:

(1) The cleaning action by cathode spots is confirmed even under a pressure as high as 20 000 Pa.

(2) The number of cathode spots on the oxide surface increased with the increase of pressure in the range of 10–20 000 Pa.

(3) The removal rate of oxide decreased with the increase of pressure.

(4) The energy density of the cathode spot decreases with the increase of pressure.

(5) The higher the pressure increases, the smaller area the migration of the cathode spot was restricted to. The migration area decreased with the increase of pressure.

(cf. *ISIJ Int.*, **46** (2006), 335)