Fundamentals of High Temperature Processes

Foaming behavior of $CaO-SiO_2-FeO-MgO_{satd}-X$ ($X=Al_2O_3$, MnO, P_2O_5, and CaF_2) slags at high temperatures

H.S.Kim et al.

The foaming index was measured for $CaO-SiO_2-FeO-Al_2O_3$ and $CaO-SiO_2-FeO-MgO_{satd}-X$ ($X=Al_2O_3$, MnO, P_2O_5, and CaF_2) slags to understand the foaming behavior. The foaming index of the $CaO-SiO_2-FeO-10Al_2O_3$ slags (C/S=0.93 and 1.2) decreases with increasing content of FeO up to 20% and is almost constant for FeO content through 20 to 40%. The viscosity of slags could be considered as the major contributor to foaming behavior. The addition of Al_2O_3 into the silicate slags results in an increase of foaming index due to an increase of slag viscosity; this could be explained by the structural role of Al_2O_3 in aluminosilicate slags. In the MgO-saturated and Al_2O_3-containing slags, FeO behaves as an acidic oxide, because slag melts would be more basic than MgO-saturated and non-Al_2O_3 slags, where FeO behaves as a basic oxide, due to Al_2O_3 enhances the dissolution of MgO into the slags. The addition of MnO into the MgO-saturated slags decreases foaming index, simply due to a decrease of slag viscosity. However, the addition of CaF_2 and P_2O_5 into the slags results in the complex foaming behavior of slags; this is probably due to the Marangoni effect. The relationships between foaming index and the physical properties of slags can be obtained from the dimensional analysis as follows:

$$\Sigma=214\frac{\mu}{\sqrt{\rho\sigma}} \quad \text{(for the CaO-based slags)}$$

$$\Sigma=999\frac{\mu}{\sqrt{\rho\sigma}} \quad \text{(for the MgO-saturated slags)}$$

The foam height is predicted as a function of decarburization rate from the molten iron and the contribution of slag foaming in EAF process was discussed as a function of decarburization rate.

(cf. *ISIJ Int.*, **41** (2001), 317)

Ironmaking

Behavior of pulverized coal ash and physical property of dripping slag under high pulverized coal injection operation

M.Ichida et al.

Based on the analysis of tuyere sampling performed in PCR increasing stage of Muroran No. 2 blast furnace of Hokkai Iron & Coke Corporation, examination was made on the influence of ash originated in pulverized coal in high-productivity, high PCR operation upon physical property of dripping slag or packed structure at dead man surface extending from raceway end. The amount of dripping slag with which ash originated in pulverized coal reacts and assimilates is 15–20% of the total amount of dripping slag, and the components of dripping slag distribute in a circumferential direction between inside of raceway and outside of raceway as well as in a radial direction including the inside of raceway and dead man. When PCR is high, high-vicious −1 mm fine at the dead man surface from the vicinity of raceway and high CaO/SiO_2 −1 mm fine and dripping slag between raceway and in dead man, with the increase of −3 mm fine, are supposed to be one of the main causes deteriorating the gas and liquid permeabilities at the dead man surface and lowering the dead man temperature. For establishing a technology assuring a stable furnace operation over a long period, it is necessary to take the measures for improving deterioration in gas and liquid permeabilities at the dead man surface due to not only −3 mm fine and unburnt char but also pulverized coal ash.

(cf. *ISIJ Int.*, **41** (2001), 325)

Cementite formation in CH_4-H_2-Ar gas mixture and cementite stability

J.Zhang et al.

Iron ore reduction/cementation by CH_4-H_2-Ar gas (35 vol% CH_4, 55 vol% H_2 and 10 vol% Ar) was examined in a fixed bed reactor in the temperature range of 600–925°C. Iron oxides were first reduced to metallic iron and then iron was carburised to cementite. The rate of iron ore reduction and iron cementation increased with increasing temperature. Iron carbide formed in the reduction/cementation process was unstable and decomposed to metallic iron and carbon. Cementite stability was studied in the temperature range of 500–850°C. At temperature below 600°C and above 750°C, the rate of cementite decomposition increased with the increase in temperature. However, in the range of 600–750°C the rate of cementite decomposition decreased with increasing temperature. Cementite was the most stable at 750°C and least stable at 600°C. At 750°C, iron ore was converted to cementite by gas containing 35 vol% CH_4, 55 vol% H_2 and 10 vol% Ar in 15 min.

(cf. *ISIJ Int.*, **41** (2001), 333)

Effect of sulphur on iron carbide formation and stability

J.Zhang et al.

Effect of sulphur on iron carbide process was investigated by examining iron ore reduction, iron cementation and cementite decomposition under gas atmosphere with and without sulphur. Sulphur added to H_2-Ar gas in the form of H_2S slightly decreased the rate of iron ore reduction at 750°C, but had a negligible effect at 850°C.

Sulphur strongly retarded iron cementation. At 850°C, cementite was formed in 10 min by sulphur-free gas, 100 min when gas contained 50 ppm H_2S, and 180 min when H_2S was in the amount of 100 ppm. The rate of cementite formation increased with increasing temperature from 750°C to 925°C.

Sulphur also strongly retarded free carbon deposition and stabilised cementite. However sulphur had no significant effect on the rate of cementite decomposition when it was introduced to the gas atmosphere after the completion of the cementation process.

(cf. *ISIJ Int.*, **41** (2001), 340)

Casting and Solidification

Numerical prediction of the secondary dendrite arm spacing using a phase-field model

M.Ode et al.

The secondary arm spacing in Fe–C, Fe–P, Fe–C–P and Al–Cu alloys are numerically predicted using a phase-field model. The calculated arm spacing and the exponent of the local solidification time are compared with the experimental data. Each calculated exponent differs depending on Fe-base or Al-base alloys. The change in the arm spacing and the exponent depending on alloy is systematically examined by the imposing artificial sets of physical properties. Interface energy and solute diffusivity in liquid change the arm spacing but not the exponent. On the other hand, liquidus slope and partition coefficient change both the arm spacing and the exponent. The change of the exponent is discussed by examining the process of deriving the value of 1/3 in the analytical model by Kattamis *et al.* and the expression for the estimation of the exponent is proposed.

(cf. *ISIJ Int.*, **41** (2001), 345)

Transformations and Microstructures

Effect of thermal cycling on microstructures and mechanical properties of lath and lenticular martensites in Fe–Ni alloys

S.-B.Seo et al.

Effects of thermal cycling on the microstructures and mechanical properties of Fe–15%Ni and Fe–31%Ni alloys having lath and lenticular martensite, respectively, have been studied. The average width of laths in lath martensite of Fe–15%Ni alloy decreased with the increase in number of thermal cycles, and the width of internal twins in lenticular martensite of Fe–31%Ni alloy also decreased with thermal cycling. The hardness of martensite increased up to 3 thermal cycles in Fe–31%Ni alloy, over which it remained constant. On the other hand, the hardness of martensite in Fe–15%Ni alloy increased up to 1 cycle, and remained nearly constant on further cycles. The tensile strength of martensite in Fe–31%Ni alloy increased up to 3 cycles, showing a similar tendency of the hardness variation. However, the tensile strength of martensite in Fe–15%Ni alloy decreased with increasing the number of thermal cycles in spite of the increase in hardness with thermal cycling. The reason is that no strain hardening occurred in the thermal-cycled specimens owing to the brittle fracture due to the segregation of sulfur at prior austenite grain boundaries.

(cf. *ISIJ Int.*, **41** (2001), 350)

Possible effect of Co on coarsening of $M_{23}C_6$ carbide and orowan stress in a 9% Cr steel

A.Gustafson et al.

It has long been known that a cobalt addition increases the resistance to tempering in steels. This may be due to the fact that Co raises the Curie-temperature which retards diffusion. In the present work the effect of Co on coarsening of $M_{23}C_6$ in the 9%

Cr steel P92 is studied by computer simulations. The results show that a final average radius of the carbides after 30 000 h at 600°C decreases with 30% with a Co addition of 10 mass%. This raises the Orowan stress with 30%. Moreover, it is assumed that slower particle coarsening also leads to a retarded coarsening of the martensite lath structure.

(cf. *ISIJ Int.*, **41** (2001), 356)

Dimensional changes and microstructural evolution in a B-bearing steel in the simulated forming and quenching process

M.C.Somani et al.

To improve the modelling of the behaviour of steel profiles in the forming and quenching process, the influences of high-temperature plastic deformation and applied stress on the martensitic transformation were investigated in a B-bearing steel by dilatometric measurements and compression tests. The plastic deformation of austenite was found to enhance ferrite formation so significantly that the dilatation due to the low-temperature transformation decreases even at a cooling rate of 280°C/s. The presence of ferrite in the microstructure results in markedly lower hardness and flow stress than the completely martensitic microstructure. Possibilities to avoid ferrite formation have been discussed. Stress applied during the martensitic transformation increases diametric dilatation by as much as 200% under axial compression, which seems to result from the preferred orientation of the martensite formed. However, subsequent to a high-temperature plastic deformation, the influence of applied stress remains much smaller.

(cf. *ISIJ Int.*, **41** (2001), 361)

Creep stress effect on the precipitation behavior of Laves phase in Fe–10%Cr–6%W alloys

J.Cui et al.

Effect of creep tensile stress on the precipitation behavior of Laves phase in Fe–10%Cr–W alloys has been investigated. Fe–10%Cr–W alloys are basic alloys of ferritic heat resisting steels, which have been being developed for the ultra-super critical pressure power generating plants. It has been clarified that the creep tensile stress enhances the Laves phase precipitation comparing with that in the same alloys aged under no stress.

(cf. *ISIJ Int.*, **41** (2001), 368)

Mechanical Properties

Low temperature impact tests in austempered ductile iron and other spheroidal graphite cast iron structures

P.J.J.Ratto et al.

Impact tests at low temperatures were carried out, aimed at comparing the response of five spheroidal graphite (SG) cast iron with different microstructures and to analyze the influence of the solidification structure size. "Y" blocks with two different thicknesses (13 and 75 mm) were cast using the same industrial melt. The following matrix microstructures were obtained by applying different heat treatments: pearlitic–ferritic (as-cast condition), fully ferritic (sub-critical annealing), fully pearlitic (normalizing) and two ausferritic matrices (ADI grades 2 and 4). Charpy impact tests were performed on unnotched specimens at temperatures ranging from −100°C to +200°C. The results showed a little variation of the upper and lower shelf energy values with the solidification structure size for each matrix type. However, there was a strong displacement in the transition temperature towards increasing temperatures as the solidification structure size enlarged. This effect is also related to the matrix microstructure. The highest impact energy values were obtained on ADI grade 2 samples, and the lowest ones on the samples with pearlitic matrix.

(cf. *ISIJ Int.*, **41** (2001), 372)

Prediction for crack propagation and arrest of shear fracture in ultra-high pressure natural gas pipelines

H.Makino et al.

Prevention of shear fracture in the natural gas pipelines is one of the most important problems for the safety of the natural gas transportation. The present paper gives a prediction method for the crack propagation and arrest in the ultra-high pressure pipelines which is the recent trend of the pipeline design and the toughness requirements for the high-grade line pipes to avoid the fracture.

(cf. *ISIJ Int.*, **41** (2001), 381)

Natural gas decompression behavior in high pressure pipelines

H.Makino et al.

This paper gives the analysis in the natural gas decompression behavior in pipelines as one of the important items for predicting the fracture safety of latest high-pressure natural gas transmission. By combining "British Gas Theoretical Model of Rich Gas Decompression" and "BWRS Equation of State", authors successfully developed the computational program, which can calculate dual-phase decompression curves of the natural gases. In the calculated results, the phenomenon of the "plateau" in the dual-phase decompression curve has been confirmed. Authors also numerically simulated the natural gas decompression behavior in pipelines and analyzed the fracture initiation process. It was shown that the initiation period is too short to influence the gas decompression curves.

(cf. *ISIJ Int.*, **41** (2001), 389)