（＊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

Effect of microwave treating the blast furnace slag bearing titanium on thermal action

L.WEN et al.

Based on the selective heating speciality of microwave, the effects of the BF slag bearing titanium heated by microwave are studied through experiment. The results indicate that the $CaTiO_3$ which crystal grains grow up speedily is a better kind of absorption material for microwave. The changing regularity of temperature and thermal stress along with heating time in the slag specimen are analyzed by numerical simulation. It can be found that the temperature of slag specimen increases rapidly in the microwave radiation field. The maximum temperature of the $CaTiO_3$ heated about 150 s in microwave power of 750 W in slag specimen reaches 868°C, and its maximum temperature can be heated up to 1 280°C in microwave power of 2 000 W within 150 s. At the same time, the thermal stress in the interface of slag specimen increased.

(cf. *ISIJ Int.*, **47** (2007), 1239)

The effect of silicon on the high temperature oxidation behavior of low-carbon steels containing the residual elements copper and nickel

B.A.WEBLER et al.

This study investigates effects of silicon on copper- and nickel-rich phases during the oxidation of iron-based alloys containing 0.3 wt% copper and 0.3 wt% copper +0.15 wt% nickel in addition to steel samples containing various amounts of copper (0.17–0.41 wt%), nickel (0.03–0.13 wt%), and silicon (0.03–0.12 wt%). Samples were exposed to air at 1 150°C for 60, 300, and 600 s. A low-carbon steel sample (0.02 wt% silicon) without copper and nickel was subjected to the same conditions for comparison.

The oxidation rates of copper- and nickel-containing steels decreased with time and were consistently lower than the rate of the residual-free low-carbon steel. An internal oxide layer was observed only in the copper- and nickel-containing steels. The number of internal oxides in this layer increased with oxidation time and larger internal oxides in this layer were characterized to be rich in iron and silicon. Compared to the iron–copper–nickel alloy, steels containing copper, nickel, and silicon, had more copper-, nickel-rich material found as particles entrapped in the oxide.

It is proposed that the population of internal silica particles increases due to increasing oxygen content near the oxide/metal interface. The rise in oxygen content results from increased oxygen solubility caused by copper and nickel enrichment. These internal oxides decrease oxidation rate and assist occlusion. An increase by a factor of 10 in amount of occluded material was measured in material containing copper, nickel and silicon compared to copper and nickel.

(cf. *ISIJ Int.*, **47** (2007), 1245)

Effect of Ti de-oxidation on solidification and post-solidification microstructure in low carbon high manganese steel

N.KIKUCHI et al.

This paper investigates the effect of de-oxidation inclusions on micro-structure in low-carbon steels. Low carbon (0.07 wt%), high Mn (0.9 wt%) steel in a Al_2O_3 or MgO crucible was deoxidized by adding either aluminum (0.05 wt%) or titanium (0.05, 0.03 or 0.015 wt%) in a 400 g-scale vacuum furnace, and cast in a Cu mold at cooling rates between 2.0–6.0 K/s.

The oxide inclusions were identified as Al_2O_3 (1–3 μm) in the Al-killed steel and Ti–Al–(Mg)–O (0.3–0.5 μm) in the Ti-killed steel. Oxide inclusion sizes in all the Ti-killed steels were smaller and inclusion densities higher than those in the Al-killed steel.

Solidification structure, defined as the density of primary dendrite arms within a defined region was finer with increasing inclusion density and as a result, the solidification structure of the Ti-killed steel was finer than that of the Al-killed steel.

A Confocal Scanning Laser Microscope (CSLM) and a Differential Scanning Calorimeter (DSC) were used to study the differences in solid state microstructural evolution between the Ti-killed, Al-killed and the non de-oxidized samples. The growth of austenite grains were studied under isothermal conditions and it was found that both grain-boundary mobility and final grain size were lower in the Ti-killed sample than for the others. With regards to austenite decomposition, during continuous cooling from a comparable austenite grain structure, the resulting austenite decomposition structure was finer for the Ti-killed sample due to a higher Widmanstätten lath density due to precipitation at particles in addition to grain boundaries.

(cf. *ISIJ Int.*, **47** (2007), 1255)

The transient stages of inclusion evolution during Al and/or Ti additions to molten iron

H.MATSUURA et al.

This study investigates the evolution of inclusions as a result of Al and Ti additions to molten Fe at 1 873 K with the objective of elucidating the transient stages of inclusion formation during ladle processing of IF steel melts. The effects of order of addition, time after addition, Al/Ti ratio and oxygen content are evaluated through an experimental approach that involves de-oxidation and sampling inside a vacuum induction furnace under conditions where the total oxygen concentration of the melt and samples are maintained constant. Each sample is analyzed for chemistry and resulting inclusion characteristics (size, morphology and chemistry). All experiments were carried out under the thermodynamic condition that Al_2O_3 was the only stable inclusion. The following results were found. Firstly, the equilibration time of Al was found to be faster than that of Ti under the present experimental conditions and as a result Al_2O_3 forms initially when Al and Ti were simultaneously added. The addition of Ti results in the formation of oxide inclusions containing Ti up to 20 mol% as a result of local Al depletion and Ti-supersaturation. This was enhanced in terms of the fraction of Ti containing inclusions as the Ti content was increased. Ultimately, in all samples, the thermodynamically stable inclusion Al_2O_3 was predominant within 5 min, but the morphology of these final inclusions were of polygonal shape rather than the spherical inclusions that formed immediately after Al de-oxidation. This modification in shape could have consequences on clogging, during post ladle teeming and pouring, in continuous casting as the tendency for agglomeration would be expected to increase.

(cf. *ISIJ Int.*, **47** (2007), 1265)

Detailed structure elucidation of the blast furnace slag by molecular dynamics simulation

K.SHIMODA et al.

The chemical structure of an amorphous slag with blast furnace composition was investigated by means of molecular dynamics simulation. Our calculation suggested that the slag had a depolymerized network of SiO_4 and AlO_4 tetrahedra with interstitial cations, Ca^{2+} and Mg^{2+}. The structural properties such as average coordination number obtained at 300 K were in good agreement with a recent NMR study, supporting the feasibility of the structure prediction by such simulation technique. At 1 873 K, the coordination numbers of the ions almost remained unchanged, while the intertetrahedral angles were found to be narrower, and the Q^n distribution of AlO_4 tetrahedra was slightly modified. The small amount but significant incorporation of MgO and Al_2O_3 influences the network connectivity, which should affect macroscopic properties such as viscosity.

(cf. *ISIJ Int.*, **47** (2007), 1275)

Ironmaking

Optical line scan inspection system for pseudo-particle analysis

J.-L.MOU et al.

A pseudo-particle size analysis instrument by optical line scan technology has been developed. The developed system composes of four major modules, which are materials feeding module, image acquired module, vision procession module and control unit. The main advantages of this system include total analysis without overlapping or missing of slipping particles, and pseudo-particle separation without breaking the granulation structure. The information gathered from the results covers pseudo-particle size distribution, mean size, roundness, sphericity, and uniformity. This is a powerful instrument for any kinds of small particle analysis.

(cf. *ISIJ Int.*, **47** (2007), 1280)

Casting and Solidification

Interaction between iron droplets and H_2S during solidification: Effects on heat transfer, surface tension and composition

P.NOLLI et al.

In strip casting the heat extraction rate is limited by the thermal resistance at the interface between solidified shell and the mold (rolls for twin-roll strip

casters). The objective of this work was to assess the effect of the use of atmospheres with gaseous species containing sulfur on the heat transfer rate experienced during droplet solidification against a water-cooled copper mold. This issue was addressed by the use of experimentation in which liquid Fe droplets solidified in direct contact with a copper chill substrate under an atmosphere of Argon mixed with a 95/5 mixture of H_2 and H_2S. The effect of the atmosphere composition was assessed by measuring in-mold heat transfer rates during solidification and by characterizing the solidified samples by sulfur printing and Scanning and Auger electron microscopy. The results were compared to those obtained using pure Fe in 95/5 atmosphere of Ar/H_2. It was found that heat transfer rates were higher when the gas atmosphere contained H_2S, result that can be explained by the decrease of the melt surface tension or the increase of the liquidus–solidus temperature difference due to the pick-up of sulfur from the gas phase into liquid iron.

These results suggest that sulfur-containing atmospheres could be used to affect heat transfer rates in strip casting. To further explore this possibility, a simple model was developed in order to predict the change of melt surface tension and the change of sulfur content in the final product when also H_2S is used in the shrouding atmosphere above the liquid pool of a twin-roll strip caster.

(cf. *ISIJ Int.*, **47** (2007), 1284)

Effect of transition metal oxides on radiative heat transfer through mold flux film in continuous casting of steel

J.DIAO et al.

Mold fluxes containing transition metal oxides, FeO and MnO, were designed based on the composition of commercial mold fluxes. Infrared transmittances of disc flux samples were measured with an FTIR spectrometer at room temperature. Extinction coefficient and absorption coefficient were calculated using Beer's Law. A radiative heat exchange model was developed. The relationship between the radiation heat flux and the content of transition metal oxides was determined by experiment and analyzed using the model. The result indicates that adding MnO and FeO has a negative effect on radiative heat transfer through disc flux samples. The radiation heat flux through the MnO and FeO containing samples was 20–50% smaller than that through basic fluxes. The decrease in radiation heat flux was attributed to the changing of molecular structure and crystallization of the fluxes. Mn_2SiO_4, Fe_2SiO_4 and other minor phases were also found in the samples containing MnO and FeO, respectively.

(cf. *ISIJ Int.*, **47** (2007), 1294)

Forming Processing and Thermomechanical Treatment

A finite element-based on-line model for the prediction of deformed roll profile in flat rolling

K.H.YUN et al.

A sound model for the prediction of the deformed roll profile during rolling is vital for the precision control of the profile and shape of the product. In this paper, the prediction accuracy of the conventional models is examined, using the predictions from the finite element model as benchmarks. Then, it is shown that a new, precision on-line model can be developed on the basis of the finite element model. The prediction accuracy of the new model is demonstrated through comparison with the predictions from the finite element model.

(cf. *ISIJ Int.*, **47** (2007), 1300)

Effect of atmospheric conditions on copper behaviour during high temperature oxidation of a steel containing copper

Y.KONDO

Copper in steels causes a hot shortness problem and it is important to know copper behaviours during high temperature oxidation in order to control the enriched copper amount. In this paper, the effects of atmosphere conditions on the copper behaviours during oxidation of a steel containing 0.1% copper are investigated. Oxidation in a dry atmosphere with oxygen has the effect of decreasing the enriched copper concentration at the scale/metal interface and broadening the copper concentration at the same point. Copper evaporates through the scale when a steel containing copper is oxidized in a low oxygen concentration atmosphere with water vapour. The oxidation in the low oxygen concentration atmosphere reduces the amounts of enriched copper at the scale/metal interface.

(cf. *ISIJ Int.*, **47** (2007), 1309)

Surface Treatment and Corrosion

Service life estimation of reinforced concrete structures made using Cr-bearing rebars in microcell corrosion environments

S.-H.TAE et al.

Reinforced concrete structures made using Cr-bearing rebars subject to microcell corrosion were assumed with the aim of developing Cr-bearing rebars having the required corrosion resistance in microcell corrosion environments. Their service lives were then estimated for each type of corrosion environment based on a microcell corrosion rate model, and requirements for Cr-bearing rebars to achieve a service life of over 100 years were calculated. As a result, the service lives of concrete structures reinforced with Cr-bearing rebars were found to increase as the Cr content increased in all types of corrosion environments. Also, Cr-bearing rebars with Cr contents of not less than 11% and not less than 7% ensured service lives of over 100 years in harsh and moderate chloride attack zones, respectively. In carbonation zones, a Cr content of not less than 3% was proven to provide corrosion resistance for over 100 years.

(cf. *ISIJ Int.*, **47** (2007), 1315)

Corrosion resistance of Cr-bearing rebar in simulated concrete pore solutions

S.-H.TAE et al.

As a fundamental study on the Cr-bearing rebar with the necessary corrosion resistance for use in steel reinforced concrete structures under corrosive environments This study was investigated to corrosion resistance of Cr-bearing rebars in simulated concrete pore solutions with content of chloride ion. The rebars were made from steels containing Cr from 0 to 16%. SUS304 stainless steel and SD345 carbon steel were also used. Simulated concrete pore solutions were saturated with $Ca(OH)_2$, containing 0.27%, 1.07% and 21.4% NaCl. The pH value of the solutions was adjusted to 12.5, 11, 10 and 9 by HCl. Pitting potential and impedance, corrosion morphology of the steels in the solutions were investigated.

The results of the study showed that the corrosion resistance increased as the Cr content increased regardless of the content of chloride ions, and that the Cr-bearing rebars with a Cr content of 5C% and 9% showed good corrosion resistance in 1.07% NaCl solutions at pH 12.5 and pH 10, respectively. Cr-bearing rebar with a Cr content of 16% showed as good corrosion resistance as SUS304 steel even in 21.4% NaCl solutions at pH 10.

(cf. *ISIJ Int.*, **47** (2007), 1324)

High-temperature oxidation behavior and scale morphology of Si-containing steels

K.KUSABIRAKI et al.

The Fe–Si alloy system is very important in steel production because silicon is often added to high-strength steel, heat-resistance steel, and other steel types. However, Si-containing steels form un-removable scales on the surface at high temperatures, and the scales allow unfavorable surface bruises in hot-rolled steels. Although many studies have been conducted on the oxidation of Si-containing steel at high temperatures, the oxidation behavior and scale morphology have not been clarified adequately.

In this study, the high-temperature oxidation behavior and scale morphology of Si-containing steels (0, 0.5, 1.5, and 3.0 mass%) exposed to the air and an LNG combustion gas atmosphere at 1 373 K and 1 473 K were investigated. The external scale and internal scale formed on Si-containing steels were composed of laminated α-Fe_2O_3 and Fe_3O_4 and a mixture of FeO and Fe_2SiO_4, respectively. The subscale may have been composed of vitreous SiO_2. The kinetics of the external and internal scale growth followed parabolic rate laws. The SEM images of the three-dimensional subscale extracted from the oxidized steels by means of an organic solvent system dissolution technique showed that an intergranular oxide formed thin walls along not only the grain boundaries but also the twin boundaries of the steel matrix, and isolated intragranular oxide particles were formed in the steel grains near the internal scale.

(cf. *ISIJ Int.*, **47** (2007), 1329)

Transformations and Microstructures

A newly-developed high wear resistant cast hot-forging die steel

S.WANG et al.

The alloying design of the cast hot-forging die

steels was analyzed. The key property and parameters for the alloying design were selected. The cast hot-forging die steel with high wear resistance was developed through optimizing the parameters. The wear resistance of the newly-developed cast die steel was evaluated in comparison with commercial H13 steels and 3Cr2W8V steel. The wear mechanism is also discussed. The newly-developed cast die steel takes VC as predominant carbide with solid solution strengthening of Cr and Mo. The cast die steel was found to have significantly lower wear rate than normal H13 steel and 3Cr2W8V steel, and almost the same wear rate as high-purified H13 steel. The high wear resistance of the new-developed cast die steel could be attributed to the reasonable alloying design and no sensitivity to detrimental function of S and P. Under the elevated-temperature air at 400°C, the wear for the cast die steels and commercial hot-forging die steels is a typical oxidation wear.

(cf. *ISIJ Int.*, **47** (2007), 1335)

Some microstructural aspects of bainite in high-carbon Si–Mn steels

F.FAZELI et al.

The microstructural characteristics of the bainite constituent associated with TRIP steels were investigated in detail by means of transmission electron microscopy (TEM). Two Si–Mn steels were selected for the study, *i.e.* a 0.6C–1.5Mn–1.5Si and a 0.18C–1.55Mn–1.7Si (wt%). Following austenitizing treatment the high carbon steel was cooled directly to bainite reaction temperature, whereas the low carbon steel was subjected to an intercritical holding step, *i.e.* in order to form polygonal ferrite prior to bainite transformation. Partially reacted samples at the bainite stage were examined in particular to determine the tendency of carbide precipitation at different transformation temperatures. Cementite particles were found in most of the analyzed conditions despite the high Si content of the specimens. The orientation relationship between cementite and bainitic ferrite was determined to be different from the frequently observed Bagaryatski relationship. The formation of cementite was rationalized in terms of its thermodynamic affinity as well as from a kinetic viewpoint. The findings strongly suggest that the common perception of carbide-free bainite pertinent to TRIP steels is not necessarily a valid assumption and thus carbide precipitation should not be neglected in a kinetic model and for designing the processing parameters for this class of advanced high strength steel.

(cf. *ISIJ Int.*, **47** (2007), 1341)

Microstructure and mechanical properties of heat-affected zone of high nitrogen steel simulated for laser welding conditions

L.ZHAO et al.

In order to obtain some information on the weldability of high nitrogen steel (HNS), the microstructure and mechanical properties of the heat-affected zone (HAZ) of HNS under laser welding conditions were investigated by using thermo-simulation technique. The experimental results indicate that the microstructure in the simulated HAZ of HNS consists of austenite and δ-ferrite that occurs in the grain boundary of austenite. The hardness of the simulated coarse-grained heat-affected zone (CGHAZ) increases when the cooling rate increases, and that of the simulated HAZ decreases while the peak temperature decreases. The results also show that the hardness of the simulated HAZ is higher than that of the base metal, indicating no softening of the HAZ under appropriate welding conditions. The impact toughness of simulated CGHAZ increases at first and then decreases with the increase of the cooling rate, whereas two brickle zones exist in the HAZ.

(cf. *ISIJ Int.*, **47** (2007), 1351)

Formability of C–Si–Mn–Al–Nb–Mo ultra high-strength TRIP-aided sheet steels

K.SUGIMOTO et al.

Formable 980–1 470 MPa grade ultra high-strength TRIP-aided sheet steels with bainitic ferrite matrix (TBF steels) have been developed for cold forming of automotive applications. Complex additions of 1.0%Al–0.05%Nb–0.2%Mo to 0.2%C–1.5%Si–1.5%Mn base steel increased both the volume fraction and carbon concentration of retained austenite films of the TBF steel, with refining of microstructure. Extremely much retained austenite was realized in the TBF steel austempered at 450–500°C, corresponding to hot-dip galvanization just after annealing. Good combinations of strength and elongation and strength and stretch-flangeability were achieved when the TBF steel was austempered at 450–500°C and 425–475°C, respectively. These good combinations were caused by fine lath structure and a large amount of metastable retained austenite film. It is noteworthy that the TBF steel exhibited an excellent combination of total clongation and stretch-flangeability when austempered at 325–350°C lower than M_S.

(cf. *ISIJ Int.*, **47** (2007), 1357)

Mechanical Properties

Temper embrittlement sensitivities of 3Cr–1Mo and 2.25Cr–1Mo low alloy steels

H.ARABI et al.

Contradicted results have been reported on sensitivities of Cr–Mo low alloy steels to fracture toughness, so it seems further investigations is required in order to establish the reasons for this contradictions. This study tried to rationalize the causes of contradiction and establishes the reasons for variations in the observed changes in fracture toughness of two types of low alloy steels namely 3Cr–1Mo and 2.25Cr–1Mo steels.

For investigating the embrittlement sensitivity in this research, a factor called J used since there are some clams that Cr–Mo low alloy steels with higher *J*-Factor are more sensitive to temper embrittlement.

For inducing temper embrittlement on these alloys, a step-cooling operation from high temperature to room temperature for a period of 234 h was employed. Then some of the mechanical properties of the embrittled sample and unembrittled alloys were determined and compared. The results showed that step cooling operation had no noticeable effect on tensile and hardness properties of the steels but strongly affected their resistance to impact. In the alloy having a low *J*-Factor of equivalent to 107, changes in both FATT and TT54J were about 11°C, this was relatively low, while in the alloy having a high *J*-Factor equivalent to 224, these changes were 70°C and 78°C respectively which indicated this alloy was highly sensitive to temper embrittlement. Changes in temper embrittlement of the two alloys used in this research were found and we tried to justify these changes in this article.

(cf. *ISIJ Int.*, **47** (2007), 1363)