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**Fundamentals of High Temperature Processes**

**Thermodynamic evaluation of the surface tension of molten CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> ternary slag**

J.-Y. CHOI *et al.*

The surface tension of CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> system at 1873 K was computed using a modified Butler's equation, and by making use of critically evaluated ionic surface distances of pure oxides involved in the system. For CaO-SiO<sub>2</sub> and CaO-Al<sub>2</sub>O<sub>3</sub> binary systems, the computed results are in good agreement with the experimental results reported by other researchers. For CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> ternary system, the surface tension in a wide range of liquid compositional range was computed and the results were favorably compared with the experimental results reported in the literature. It was found that the surface tension increases with decreasing SiO<sub>2</sub>, and with increasing CaO or Al<sub>2</sub>O<sub>3</sub>. For a given SiO<sub>2</sub> content, the surface tension was relatively independent of the CaO/Al<sub>2</sub>O<sub>3</sub> ratio. An iso-surface tension diagram has been suggested for liquid CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> solutions.

(*cf. ISIJ Int.*, 42 (2002), 221)

**Nitrogen dissociation rate at solid surface of ferrous alloys**

H. ONO-NAKAZATO *et al.*

The nitrogen dissociation rates at the surface of solid iron-M (M: Si, Al, Mn, Cr, and Ti) alloys have been measured by an isotope exchange technique at temperatures ranging from 1473 to 1798 K. From the present results, the rate constant of nitrogen dissociation at the surface of pure solid iron is derived as  $1.97 \times 10^{-5}$  [mol/(cm<sup>2</sup>·s·atm)] at 1773 K and the apparent activation energies for the nitrogen dissociation at the surfaces of  $\delta$ -Fe and  $\gamma$ -Fe ([mass ppm O]=10.3, [mass ppm S]=7) at  $P_{N_2}=0.05$  (atm) are calculated as 127 and 162 (kJ/mol), respectively. The effects of the alloying elements on the nitrogen dissociation rate at the surface of solid iron have the same tendency as those at the surface of liquid iron investigated previously by a similar method to the present study; the nitrogen dissociation rate is increased by the addition of Mn, Cr, or Ti and is decreased by the addition of Si or Al. The degree of the effects of increasing or decreasing the rate by the alloying elements for the solid iron is found to be smaller than that for the liquid iron.

(*cf. ISIJ Int.*, 42 (2002), 229)

**Ironmaking**

**Flow characteristics of a blast furnace taphole stream and its effects on trough refractory wear**

Q. HE *et al.*

An investigation consisting of plant trials and water modelling studies has been carried out with the aim of gaining a better understanding of flow characteristics of a blast furnace taphole stream and its effect on the trough refractory wear. It has been found that the entrainment of the blast gas into the taphole is the most likely root cause for splashy taphole stream, which is believed to greatly contributes

to refractory wear on the trough in the region above the liquid level and on the trough cover. Based on the findings from the present studies, changes were made to furnace operation and casting practices at BHP Steel's Flat Products Division No. 6 Blast Furnace (BF6) to minimise splashy taphole streams. As a result, the refractory wear on the trough and its cover has been significantly reduced. The trough life of BF6 has been improved, from 60 000 to 300 000 tonnes of hot metal.

(*cf. ISIJ Int.*, 42 (2002), 235)

**Lowering of grinding energy and enhancement of agglomerate strength by dehydration of indonesian laterite ore**

H. PURWANTO *et al.*

In order to utilize the iron-rich laterite as raw material for ironmaking process, the effect of dehydration on physical properties of its agglomerate was investigated experimentally. The laterite used in this experiment was produced in Sebuk Island (Indonesia) containing 50.88 mass% of iron. The laterite ore was analyzed by X-ray diffraction for its mineral composition. Differential Thermal Analysis was employed for the thermal analysis and High Temperature microscopic observation was conducted to clarify the behavior of dehydration during the thermal treatment. Agglomeration was carried out in the form of briquette and the strength was measured for laterite ore before and after preheating. Furthermore, Grinding Work Index was measured to evaluate the energy consumption for grinding operation.

X-ray diffractometry and Differential Thermal Analysis revealed that the iron mainly formed iron oxide hydrate (goethite), and it decomposed at the range of 530-673 K. High Temperature Microscopic observation explained that the dehydration resulted in crack generation. The crushing strength was measured for the briquettes prepared from the laterite with or without preheating. The improvement of crushing strength was obtained by preheating the laterite ore at 673 K for 1 h. The grinding work index for preheated laterite was obtained about 35% lower than that of no preheated original ore. Generally, the experimental results showed that preheating treatment promoted in increasing the crushing strength of briquette and decreasing energy consumption for the grinding of laterite ore.

(*cf. ISIJ Int.*, 42 (2002), 243)

**Casting and Solidification**

**Oxidation of molten steel by the air permeated through a refractory tube**

M. SUZUKI *et al.*

Refractory tubes such as a shrouding nozzle and a submerged entry nozzle are employed for molten steel transferring from a ladle to a tundish, and a tundish to a mold, respectively, to prevent molten steel from being oxidized. When the cross-sectional area in the molten steel flow channel is suddenly contracted and subsequently enlarged, a negative pressure is generated at the area. Thereby air is permeated into the molten steel flow through the refractory tube and oxidizes the molten steel.

The permeability of a submerged entry nozzle was predicted from measurement of the gas permeated through the refractory tube by a dipping test. Using the predicted permeability and the pressure analysis in fluid flow, we calculated the oxidation rate by the permeated air during molten steel transferring. As a result, the concentration decrease rate of aluminum in molten steel is estimated 0.35 ppm per hour and this oxidation formed by the permeated air does not attribute to alumina build-up in the submerged entry nozzle.

(*cf. ISIJ Int.*, 42 (2002), 248)

**Shape and count of free graphite particles in thin wall ductile iron castings**

J. M. BORRAJO *et al.*

Recently, the scientific community has begun to study in detail the potential application of ductile iron in the production of thin wall components. Efforts are focused on the identification of the operative conditions necessary to obtain parts free of defects, with the desired microstructure. These aspects have been widely examined in the past for parts of conventional thickness (more than 5 mm), either experimentally or by using computational programs to model the solidification process. Nevertheless, modeling of thin walled parts is still unreliable, since specific databases are not available.

The objective of this work is to study the evolution of the graphite nodule count and shape in ductile iron, as the section thickness diminishes down to 1.5 mm, using conventional casting procedures and resin bonded sand molds.

A reasonably accurate correlation between solidification time and nodule count has been developed, based on experimental and modeled cooling curves. The morphology of graphite nodules has been characterized by image analysis, and the results correlated with the solidification time. The advantages of using solidification time as a parameter instead of thickness are also discussed.

(*cf. ISIJ Int.*, 42 (2002), 257)

**Improvement of billet surface quality by ultra-high-frequency electromagnetic casting**

H. NAKATA *et al.*

Electromagnetic casting using ultra high frequency magnetic field (100 kHz) was investigated. At the initial stage, laboratory experiments have been made, and it is clear that oscillation marks can be totally suppressed and the homogeneity of the initial solidified shell is greatly improved. From these results, EMC has beneficial effects on preventing surface and sub-surface cracks. Furthermore, accumulation of inclusions and pinholes to the surface due to electromagnetic force does not occur, together with the electromagnetic stirring in the mold, when EMC frequency enhances to 100 kHz. Based on these results, plant trials were put into practice. As far as operational conditions are concerned, a new method of meniscus control was developed, and lubrication between the mold and the initial solidified shell is improved as the reason that friction force decreases, and mold powder consumption increases. From an investigation of the quality of rolled bars, it

was confirmed that the quality of bars rolled from EMC billet without surface conditioning is the same as that of bars rolled from conventionally cast billets with surface conditioning.

(cf. *ISIJ Int.*, **42** (2002), 264)

### The influence of Ti on the hot ductility of Nb-bearing steels in simulated continuous casting process

*H.LUO et al.*

The hot ductility of as-cast Nb, Ti and Nb-Ti bearing low-carbon steels has been assessed. Hot tensile testing of *in-situ* melted specimens, replica examinations and thermodynamic modeling showed that addition of 0.014–0.04%Ti to 0.1%C–0.03%Nb–0.005%N steel leads to a large volume fraction of fine strain-induced precipitates at temperatures up to 1 000°C which seriously deteriorate the hot ductility, in spite of the type of prior thermal history. Generally, three types of precipitates, *i.e.* coarse boundary precipitate, coarse frond-like and fine strain-induced precipitates, were found in Ti-Nb microalloyed steels with the different sizes and compositions, and the latter could be described by thermodynamic modeling. The current results are different from the previous ones published and a thermodynamic model was employed to explain this discrepancy. Accordingly, the beneficial effect of Ti can only be achieved in some instances at high nitrogen and low titanium contents, *i.e.* a low Ti/N ratio, which greatly encourages coarse precipitation at high temperatures and reduces the fine strain-induced precipitation. Therefore, only for electric arc steels typically with a high nitrogen level, a small addition of Ti might be considered to be advantageous to the hot ductility.

(cf. *ISIJ Int.*, **42** (2002), 273)

### Forming Processing and Thermomechanical Treatment

#### Convective heat transfer coefficient for high pressure water jet

*J.W.CHOI et al.*

The scale on the surface of hot rolled steel is removed by high pressure hydraulic descaling in a rolling mill. If the impact pressure of the water jet is higher, the scale is removed well. However, the temperature drop of the hot rolled steel is increased owing to the flow rate of the water jet. On this account, the temperature distribution of the hot rolled steel should be analyzed during the process of the hydraulic descaling. However, the analysis of the temperature distribution is difficult due to lack of the literatures on the convective heat transfer coefficient for the high pressure water jet. In the present study, the hydraulic descaling system is manufactured and the impact pressure is deduced from the

relationship between spray pressure and spray height. And then the equation of the convective heat transfer coefficient is induced by the function of the impact pressure. The convective heat transfer coefficient is obtained from the experimental values by the hydraulic descaling system and the values calculated by numerical analysis. The equation of the convective heat transfer coefficient will aid to establish the most suitable conditions for operations in the rolling mill.

(cf. *ISIJ Int.*, **42** (2002), 283)

### Welding and Joining

#### Weldability and microstructural aspects of shielded metal arc welded HSLA-100 steel plates

*S.K.DHUA et al.*

HSLA-100 steel with 14 mm thickness in quenched and tempered condition was shielded metal arc welded (SMAW) with 2 kJ/mm heat input using basic flux coated filler rods without any pre or post welding heat treatments. The steel was found to be welded satisfactorily in this condition without developing any defect. Optical microscopy studies revealed typical cast dendritic structure in the weld metal and coarse bainite in grain-coarsened area of the heat-affected zone (HAZ). Transmission electron microscopy (TEM) study confirmed incidence of mixed structure of martensite laths and bainite in weld metal, while, it was mainly of bainite laths in HAZ with evidence of martensite-austenite (M-A) constituent and massive ferrite. The yield strength (YS), ultimate tensile strength (UTS) and Charpy V-notch (CVN) impact energy of the weld metal (YS-695 MPa, UTS-842 MPa and CVN-105 J at -50°C) and HAZ (YS-790 MPa, UTS-891 MPa and CVN-130 J at -50°C) were found satisfactory although HAZ properties were inferior to the base metal properties. The hardening of HAZ was not very significant in this steel under the present welding condition.

(cf. *ISIJ Int.*, **42** (2002), 290)

### Transformations and Microstructures

#### The effect of processing history on a cold rolled and annealed Mo-Nb microalloyed TRIP steel

*S.JIAO et al.*

In this paper, a Mo-Nb microalloyed TRIP Steel was subjected to several heat treatments designed to generate different microstructures. These microstructures were then cold rolled and TRIP-annealed, and the resulting tensile properties and retained austenite characteristics were determined. The results reveal that prior heat treatment has a significant effect on the cold rolled and annealed behavior. Generally, an increasing volume fraction of

proeutectoid ferrite prior to cold rolling and TRIP annealing leads to improved tensile ductility. This is due to increased work-hardening rates, which, in turn, correlate to increased carbon enrichment in the retained austenite. These results can clearly be used to optimize the hot rolling process to produce hot strip for the subsequent production of cold rolled Mo-Nb TRIP Steel.

(cf. *ISIJ Int.*, **42** (2002), 299)

#### The influence of martensite on line broadening in neutron diffraction spectra of a DP steel

*R.FILIPPONE et al.*

Neutron diffraction experiments were performed on dual-phase steels to determine the feasibility of measuring the martensite volume fraction through ferrite peak broadening. Mechanical properties were also investigated to determine if a correlation exists with ferrite peak broadening. Results indicate that the correlation between martensite volume fraction and ferrite peak broadening is carbon dependent. Furthermore, two mechanisms regarding the nature of the ferrite peak broadening in dual-phase steels are proposed. Tensile testing demonstrated that a correlation between peak broadening and mechanical properties exists for dual-phase steels.

(cf. *ISIJ Int.*, **42** (2002), 304)

### Mechanical Properties

#### Fatigue behaviour of new duplex stainless steels upgraded by nitrogen alloying

*K.MASSOL et al.*

The fatigue behaviour of two duplex stainless steels (DSS) alloyed with different nitrogen contents (0.24 and 0.4 wt%) has been studied in air and in a NaCl-containing water solution. Both of the alloys exhibit a cyclic softening preceded by a cyclic hardening at high strain amplitude as reported in the literature for lower nitrogen grades. In air, the fatigue lives are nearly the same for both of the DSS for any given strain amplitude. In the corrosive environment, the fatigue life was systematically reduced by a factor two for the 0.24% N-containing DSS in the strain range studied in contrast with the 0.4% N-containing DSS which appeared to be all the more insensitive as long as the strain amplitude was small. The fatigue resistance and the cyclic accommodation of these DSS are strongly controlled by the volume fraction of  $\alpha$  and  $\gamma$  phases. It is shown that DSS with a high fraction of austenite present a good combination of fatigue resistance and cyclic softening. Alloying with nitrogen appears to be a promising way to master an optimised microstructure leading to high mechanical resistant DSS.

(cf. *ISIJ Int.*, **42** (2002), 310)