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## Fundamentals of High Temperature Processes

### Gas injection from slot nozzles with various shapes in water

*K.OKUMURA et al.*

Results of experiments examining behaviour of gas bubbles detouching from slot nozzles of various shapes are presented. Gas was injected into water through the slot nozzles of 200 mm in length and 0.05, 0.1 mm in width. Four types of the slot nozzles were used: (a) flat nozzle, (b) mountain-shaped nozzle, (c) valley-shaped nozzle, (d) unilaterally inclined nozzle. They were made of Teflon which is poorly wetted by water. The bubble behavior is described by two parameters: bubble diameter formed at the slot nozzle and the number of bubble sources. It was found that the gas injection through the mountain-shaped nozzle produces the smallest bubble while the largest bubble is formed when the valley-shaped nozzle is used. Bubbles produced at the flat nozzle and unilaterally inclined nozzle were almost the same in size which is intermediate between the bubble sizes for the mountain-shaped and valley-shaped nozzles. Comparative experiments showed that, when gas is injected through a wetted slot nozzle, the bubble size is much smaller than that for the nonwetted slot nozzle of the same design (flat nozzle) at lower gas flow rates. For all experiments, the bubbles become smaller as the number of bubble sources increased.

(cf. *ISIJ Int.*, **40** (2000), 544)

### Decomposition of $CaCO_3$ in molten borate and its effect on slag foaming behavior

*S.CHU et al.*

A model for thermal composition of $CaCO_3$ in $Na_2B_4O_7$ molten slag is presented in the paper. The experimental results show that the size of $CaCO_3$ particle and CaO content in slag have effect on foaming by gas inside the slag, and these effects are all dependent on the decomposition behavior of $CaCO_3$ in molten slag. Therefore, the foaming index, $\Sigma$, which is measured with bubbling, cannot be employed to evaluate the stability of foams from gas inside the slag.

(cf. *ISIJ Int.*, **40** (2000), 549)

### A newly developed method for determining $SiO_2$ activity of the silicate slags equilibrated with molten silicon alloys

*K.MORITA et al.*

In the determination of activities of components other than $SiO_2$ for the CaO–$SiO_2$-$AlO_{1.5}$–MgO slags equilibrated with molten Si alloys, activities of $SiO_2$ in the slags are required and their accuracy will considerably affect the results. For the CaO–$SiO_2$, CaO–$SiO_2$–$AlO_{1.5}$ and CaO–$SiO_2$–MgO slags, the activities of $SiO_2$ were obtained from the distribution of each element between slags and metals, and each thermodynamic property in molten Si alloys at 1 823 and 1 873 K using a newly developed method with the Gibbs–Duhem equation. The data obtained in the present research were compared with those reported by other investigators, and showed reasonable agreement in wide slag composition ranges. These activity data of $SiO_2$ will be employed in the subsequent determination of other component activities for the binary and ternary slag systems concerned.

(cf. *ISIJ Int.*, **40** (2000), 554)

### Activity measurement of CaO–$SiO_2$–$AlO_{1.5}$–MgO slags equilibrated with molten silicon alloys

*K.KUME et al.*

The activities of components in the CaO–$SiO_2$–$AlO_{1.5}$–MgO slags at 1 823 and 1 873 K were directly measured by equilibrating the slags with Si based alloys.

For the CaO–$SiO_2$, CaO–$SiO_2$–$AlO_{1.5}$ and CaO–$SiO_2$–MgO systems, thermodynamic properties of Si based alloys and the activity data of $SiO_2$ obtained from the distribution of each element between slags and the alloys in the previous paper were used to derive the activities of $AlO_{1.5}$, CaO and MgO. For the CaO–$SiO_2$–$AlO_{1.5}$–MgO quaternary system, the activities of components other than $SiO_2$ on the 10 mass% MgO plane were determined at 1 873 K by employing the $SiO_2$ activities available in the literature.

Accordingly, it was confirmed that the activities of components other than $SiO_2$ in multi-component silicate slag systems can be determined by this technique as long as the activity datum of at least one component in the systems is available.

(cf. *ISIJ Int.*, **40** (2000), 561)

### Rising behavior of air–water two-phase flows in vertical pipe of poor wettability

*M.IGUCHI et al.*

Bubbles and slugs rising in vertical pipes of good and poor wettability were observed with a high-speed video camera. The mean rising velocity of bubbles on the pipe center line was slightly smaller in the poor wettability pipe than that in the good wettability pipe because the attachment of bubbles to the pipe wall took place in the former pipe, while that of slugs was hardly dependent on the wettability of the pipe. The mean vertical length of bubbles on the pipe center line was slightly larger in the pipe of poor wettability than that in the pipe of good wettability due to the coalescence of bubbles on the wall of the pipe of poor wettability. However, the mean vertical length of slugs was not dependent on the wettability of the pipe. An empirical equation was proposed for the mean vertical length of slugs.

(cf. *ISIJ Int.*, **40** (2000), 567)

## Steelmaking

### Formation of fine bubble through swirling motion of liquid metal in the metallurgical container

*S.YOKIYA et al.*

In pyrometallurgical processes, creation of gas-dispersed metal system is required to promote an interfacial reaction rate at a gas-liquid metal boundary, as well as to remove non-metallic inclusions in a bulk metal. We found that fine gas bubbles penetrated easily from a container wall to a mercury bath by addition of the swirling motion which created a centrifugal force. Measured radius of bubbles in a metal bath, $B$ is in good accordance with that calculated by the following equation; $B=(1/2)^{1/3}(1/w)(2R\sigma/\rho)^{1/2}$: $w$; tangential velocity, $R$; radius of container, $\sigma$; surface tension of molten steel, $\rho$; density of molten steel. In the system, injection pressure for penetration of bubbles in the metal bath is much lower than that of conventional injection process by tuyeres and lances.

(cf. *ISIJ Int.*, **40** (2000), 572)

### Swirling flow effect in immersion nozzle on flow in slab continuous casting mold

*S.YOKOYA et al.*

With increasing requirement of steel productivity and quality in continuous casting in the conventional casting system using an immersion nozzle with side pouring holes, it is very difficult to establish a reasonable molten flow pattern. In order to overcome this difficulty, we propose a new method imparting a swirling motion to the flow in the immersion nozzle and to control the flow pattern in the mold. Obtained results are as follows:

1) High amplitudes of oscillation with a period of 10 to 15 sec are observed in the outlet flow of the immersion nozzle and meniscus flow in the conventional casting system, while these phenomena are remarkably suppressed using swirling motion in the immersion nozzle, which leads to very calm and uniform flow pattern at the outlets of the immersion nozzle, in the mold and on the meniscus in the mold.

2) The steady outlet flow softly impinges on the side wide face, and then turns around as a reverse flow along the other wide face describing a S-shaped curve in the cross section and clock-wise rotational flow in the vertical section. This outlet flow exerts a shearing-effect on the inner wall of the mold, leads to the considerable energy consumption and exerts a braking effect in the flow which results in suppression of self-excitation-vibration in the bulk mold flow and biased flow on the meniscus. In other words, imparting a swirling motion to the flow in the immersion nozzle, remarkably reasonable bulk mold flow can be obtained.

(cf. *ISIJ Int.*, **40** (2000), 578)

### Development of swirling flow generator in immersion nozzle

*S.YOKOYA et al.*

It is very critical to develop a cheap, simple and safe swirling generator because an introduction of swirl motion is very effective to control the flow in the continuous casting mold and refining process. Here, a twist-tape-swirling-blade is proposed and its characteristics are investigated. Obtained results are as follows;

(1) Numerical results obtained by the $k$–$\varepsilon$ turbulence model and experimental results coincide with each other for the tangential velocity distributions at the outlet of the swirl blade.

(2) A slightly strained tangential velocity can be seen just below the swirling blade, but the tangential

velocity becomes axi-symmetric at a downstream position, which is within the distance of 100 mm from the outlet of the swirling blade.

(3) Knowing the axial velocity and twist ratio of the swirl blade, the corresponding tangential velocity and pressure drop can be deduced through the relationship between dimensionless radial position and tangential velocity.

(cf. *ISIJ Int.*, 40 (2000), 584)

## Casting and Solidification

### Wear of roll surface in twin-roll casting of 4.5% Si steel strip

*N.ZAPUSKALOV et al.*

The rolls are one of the most important components of the twin-roll casting process, determining not only strip quality, but due to their expense, add to the price of the as-cast strip. The potential for reducing operational cost and ensuring required strip quality may be achieved through a reduction in wear of the roll surface and hence reduced frequency of roll surface reconditioning and replacement. To achieve this, it is imperative to understand the mechanisms of roll surface wear which occur during casting operations.

The present study was aimed at determining the influence of liquid metal, roll separation force and strip incline from the vertical casting direction on the wear of the roll surface in a twin-roll casting process.

It was found that roll wear in the twin-roll casting process is accompanied by removal of material from the roll surface and redistribution of topography of the roll surface. Applying high roll separation forces lead to increase erosion of the roll surface and coarsening of the roll surface topography. Roll surface wear caused by deformation occurs by imprinting of the strip surface on the roll surface as well as grinding of the roll surface by the strip. Even with the application of high roll separation forces the highest contribution to wear of the roll surface is by the interaction of the melt with the roll surface in the very early stages of solidification.

(cf. *ISIJ Int.*, **40** (2000), 589)

### Control of foaming of Al alloy melt

*S.CHU et al.*

The optimal quantity of $TiH_2$ (foaming agent) and the most suitable temperature for producing foamed Al alloy in a non-isothermal process are determined. Experimental results show that the initial foaming temperature must be higher than the solidifying point of Al alloy, and as $TiH_2$ decomposition starts, the melt temperature drops down to the solidification temperature interval, meanwhile bubbles become stable and drainage of foaming layer slows down. In the experiments, foaming temperature of 680°C and 2 wt% $TiH_2$ (<300 mesh) are the optimal combination for making foamed Al alloy of good quality. It is found that the wide solidification temperature region is an important factor for better controlling the foaming process.

(cf. *ISIJ Int.*, **40** (2000), 597)

### Inflow behavior observation of molten mold powder between mold and solidified shell by continuous casting simulator using Sn–Pb alloy and stearic acid

*K.TSUTSUMI et al.*

High productivity and high quality slab machine have been recently required in continuous casting process to lower the cost of steel production. It is important to know the inflow behavior of mold powder between mold and solidified shell to develop higher-speed casting. The purpose in this study is to make clear the mechanism of lubrication between mold and solidified shell. Sn–5mass%Pb alloy and stearic acid were used as substituted of liquid steel and molten mold powder in the experiment simulated continuous casting machine. Direct observation on inflow behavior of mold powder was made experimentally by a digital video camera. The friction force between mold and solidified shell was measured by a load cell which was set under the mold. Mold powder flowed into the aperture between mold and solidified shell during both positive strip time period and negative strip time period and the amount of powder consumption in positive strip time period was more than that in negative strip time period. The friction force between mold and solidified shell decreased when positive strip time ratio increased. When the modification rate or amplitude increased, or when frequency or casting speed decreased, the friction force decreased. These inclinations corresponded with those in the industrial continuous casting machine qualitatively.

(cf. *ISIJ Int.*, **40** (2000), 601)

## Chemical and Physical Analysis

### Advantage of argon–helium mixed gas plasmas for carbon determination in glow discharge optical emission spectrometry

*K.WAGATSUMA*

For the sensitive determination of carbon in steel samples, an argon–helium mixture plasma gas was employed in glow discharge optical emission spectrometry. The emission lines of carbon have relatively high excitation energies, which implies that the excitations by helium whose ions and metastable atoms have larger internal energies could produce the excited states of carbon more readily. Comparison in the calibration curves yields the detection sensitivity obtained with the argon–helium mixture was enhanced than with the argon gas alone by a factor of 3.

(cf. *ISIJ Int.*, **40** (2000), 609)

## Forming Processing and Thermomechanical Treatment

### Effect of silicon on the kinetics of Nb(C, N) precipitation during the hot working of Nb-bearing steels

*J.DONG et al.*

The effect of Si on the rate of Nb(C, N) precipitation was investigated by using fractional softening measurements. Compression specimens, with diameters of 7.6 mm and lengths of 11.4 mm, were prepared from four Nb microalloyed steels containing a range of Si concentrations from 0.01 mass% to 0.41 mass%. Double-hit compression tests, with a strain of 0.3 for each pass and a strain rate of 0.1/ sec., were employed. A solution heat treatment was applied immediately prior to each test. It was found that the rate of Nb(C,N) precipitation in hot deformed austenite increases with Si concentration. This phenomenon is attributed to the increases in the activities of C and N that result from Si addition.

(cf. *ISIJ Int.*, **40** (2000), 613)

### Calculation of ferrite decarburizing depth, considering chemical composition of steel and heating condition

*M.NOMURA et al.*

The calculation of ferrite decarburizing depth considering the effects of the chemical composition of steel and heating condition was attempted using a diffusion model and its propriety was confirmed by comparing with the experimental results. The calculation values of ferrite decarburizing depth were almost the same as the experimental values under most heating conditions, which indicates that the model is appropriate for simulation of the ferrite decarburizing depth considering the steel composition and heating condition. Only in the case where steel with a high proportion of titanium, vanadium and chromium was heated to under 973 K, did the ferrite decarburizing depth of the experiment show lower values than that of the calculation. It was speculated that small MC carbides as TiC or VC and chromium which stabilizes cementite affected the formation of ferrite decarburizing area.

(cf. *ISIJ Int.*, **40** (2000), 619)