

Fundamentals of High Temperature Processes

Observation of inclusion in aluminum deoxidized iron

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Aluminum-deoxidized iron at 1 873 K was solidified at 3 different cooling speed; (1) the ultra-rapid cooling of iron using twin rollers, (2) the quenching of iron into copper mold, and (3) the quenching of the iron-bearing crucible in a water bath; the most rapid cooling rate achieved with (1), which was probably about 10^5 K/s, followed (2) and (3). Dendritic, maple-like, polygonal, network-like, coral-like and spherical inclusions were observed in the samples. The dendritic, maple-like and polygonal inclusions varied in size from several tens to a few μm and were classified as primary inclusions since their sizes were independent of cooling speed. However, the network-like and coral-like inclusions (in the sample cooled ultra-rapidly and quenched into copper mold), and spherical inclusions were classified as secondary inclusions since they decreased in size with increased cooling speed. A few large spherical inclusions, which would be primary inclusions, were also present.

The analysis of the electronic diffraction of the inclusions established that the α , γ , δ -alumina were present as secondary inclusions. An amorphous silica spherical inclusion was also observed.

(cf. *ISIJ Int.*, 42 (2002), 459)

Thermodynamic analysis on metastable alumina formation in aluminum deoxidized iron based on ostwald's step rule and classical homogeneous nucleation theories

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A mechanism for the formation of unstable alumina (δ , γ , and κ -alumina) in Al-deoxidized iron has been investigated on the basis of Ostwald's Step Rule and two homogeneous nucleation theories. The two homogeneous nucleation theories include a simplified theory in widespread use and the other is a modified theory in which the Gibbs free energy change of the parent iron phase is taken into consideration.

Comparison of the chemical potential of various aluminas from the standpoint of the Ostwald's Step Rule showed that the unstable alumina could form from the liquid iron alloy supersaturated with oxygen. Moreover, the rule revealed that there is a possibility of liquid alumina formation. The two homogeneous nucleation theories also proved the possibility of the formation of unstable and liquid alumina. The latter nucleation theory indicated the easier nucleation of liquid and unstable aluminas than that for α -alumina from the liquid iron containing oxygen contents in excess of the critical value of nucleation at 1 873 K. In contrast, nucleation was rare for oxygen contents less than the critical point at 1 873 K. However, unstable alumina can be formed during cooling and solidification since the oxygen contents of the critical point decreases with temperature decrease. When iron solidifies whilst in the supercooled condition, the nucleation rates of unstable and liquid alumina can be accelerated as a result of

the oxygen enrichment at the solidifying front. The authors propose a mechanism of the network-like or coral like inclusion formation by taking into consideration of the liquid alumina formation.

(cf. *ISIJ Int.*, 42 (2002), 467)

Thermodynamics of the $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-TiO}_x$ oxide system at 1873 K

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Isothermal phase relations for the $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-TiO}_x$ system have been investigated under strongly reducing conditions, achieved by equilibrium between graphite and CO gas, $P_{\text{O}_2} = 4.56 \times 10^{-16}$ atm at 1 873 K, in equilibria with a saturating oxide tablet.

Activities of Al_2O_3 and SiO_2 were measured by the Knudsen effusion method. Activities of SiO_2 were also measured by the chemical equilibrium between the oxide and the Fe-Si-C alloy. Activity of TiO_x was also estimated from the composition of the Si-Al-Ti alloy in equilibrium with the oxide assuming that the alloy conformed to a regular solution. In addition, steel composition equilibrated with the oxide of arbitrary composition has been calculated by the activities of each component of the oxide system obtained in the present study.

(cf. *ISIJ Int.*, 42 (2002), 474)

Gaseous reduction behavior of powdered iron ore sinter and analysis on the basis of rist model for fixed bed

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For the analysis of a blast furnace process, it is necessary to investigate the reduction behavior of iron ore sinter, which is the main source of an iron oxide charged into the blast furnace. It is impossible to accurately analyze the reduction behavior of the iron ore sinter without considering the existence of a quaternary calcium ferrite (CF), which has another reduction equilibrium different from hematite. From this point of view, the gaseous reduction behavior of powdered iron ore sinter has been investigated mainly at 1 173 K and the analysis has been conducted on the basis of a model derived by modifying Rist model for a fixed bed in consideration of CF. The hydrogen reduction behavior is found to be in reasonable agreement with the reduction curve calculated from the derived model at temperatures ranging from 1 073 to 1 273 K. Subsequently, in order to confirm the validity of the derived model, the hydrogen reduction behavior of a synthesized CF, hematite, and a mixture of the CF and hematite was investigated. The trend was observed that the reduction behavior of hematite and the mixture of the CF and hematite is almost the same and that the reduction behavior of the single CF sample has a delay for the others, in reasonably accordance with the relationship derived from the model. Moreover, the reduction behavior can be almost explained by the derived model regardless of the mixture ratio of H_2 and CO in the ingoing gas under the present experimental conditions; the reduction progress has a delay by the difference of the reduction equilibrium by replacing H_2 with $\text{CO}(-\text{CO}_2)$.

(cf. *ISIJ Int.*, 42 (2002), 482)

Stability of cuspidine ($3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2$) and phase relations in the $\text{CaO-SiO}_2\text{-CaF}_2$ system

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Primary crystallization field of cuspidine ($3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2$) has been experimentally determined in the $2\text{CaO} \cdot \text{SiO}_2\text{-SiO}_2\text{-CaF}_2$ system by quenching method and differential thermal analysis (DTA). Hermetically closed platinum capsules were used as a sample container to prevent fluorine loss in the form of HF and SiF_4 by reaction of CaF_2 with moisture or SiO_2 for quenching experiments. Combining the present study with the partial phase diagrams previously reported, the whole phase diagram of the $\text{CaO-SiO}_2\text{-CaF}_2$ system has been developed. Cuspidine equilibrates with $(2\text{CaO} \cdot \text{SiO}_2)_2\text{CaF}_2$, $\text{CaO} \cdot \text{SiO}_2$, $3\text{CaO} \cdot 2\text{SiO}_2$, $2\text{CaO} \cdot \text{SiO}_2$ and CaF_2 in solid state. Cuspidine coexists with liquid phases at temperatures between 1 387 K and 1 680 K.

(cf. *ISIJ Int.*, 42 (2002), 489)

Measurement of thermal diffusivity of steels at elevated temperature by a laser flash method

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In order to obtain thermal diffusivity of steels at elevated temperature with sufficient reliability using a laser flash method, an accurate value of specimen thickness is essentially required. Accordingly, a linear thermal expansion coefficient of steels was systematically measured in the temperature range from room temperature to 1 676 K. Since the decrease in specimen thickness was detected after the measurement of thermal diffusivity under vacuum at high temperature close to solidus, such a factor was quantitatively estimated from the thickness values of quenched specimens. Combining these two results, the thermal diffusivity values were successfully determined for ultra low carbon, low carbon, medium carbon, 1.2% silicon, 9% nickel and 13% chromium steels in the temperature range from room temperature to 1 676 K using the laser flash method.

(cf. *ISIJ Int.*, 42 (2002), 498)

Ironmaking

Indicators of the internal state of the blast furnace hearth

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The hearth is a crucial region of the blast furnace, since the life of its refractory may be decisive for the campaign length of the furnace. Excessive growth of skull on the hearth wall and bottom, in turn, reduces the inner volume of the hearth, causes drainage and other problems that limit productivity, and has a negative effect on hot metal temperature and chemistry. A set of indicators that reflect the internal state of the hearth has been developed. The motivation for the indicators is outlined and their application to hearth state detection is illustrated with several examples from the operation of two Finnish blast furnaces.

(cf. *ISIJ Int.*, 42 (2002), 504)