Fundamentals of High Temperature Processes

Activities in CaO-MgO-Al_2O_3 slag and deoxidation equilibria of Al, Mg, and Ca

H. OHTA et al.

The equilibrium experiments between CaO-Al_2O_3-MgO-0.06 to 0.85% MnO-0.5 to 2.1% Fe_tO-0.07 to 0.3% S (mass content in %) slag and liquid iron were carried out at 1 823 and 1 873 K in order to assess the activities of Al_2O_3 and MgO along the spinel ($MgO \cdot Al_2O_3$) saturation line. The activities of CaO in an entire liquid region were first determined at 1 823 and 1 873 K from the reported values for sulfide capacity, coupled with the activity coefficients of CaS which were estimated from those in the CaO-Al_2O_3 slags. On the basis of these iso-activity lines for CaO, the activities of Al_2O_3 and MgO were calculated by using the method of Schuhmann, in which the assessed activities of Al_2O_3 and MgO on the spinel saturation line were taken as the starting points. The activity coefficients of Fe_tO and MnO along the spinel saturation line were determined and the deoxidation equilibria of Al, Mg, and Ca were discussed.

Ironmaking and Reduction

Effect of firing temperature and porosity on thermal conductivity and diffusivity of iron ore pellets

N.S. SUNDAR MURTI et al.

The thermal diffusivity and conductivity of iron ore pellet were determined by measuring temperature at surface and centre of pellet during heating and applying heat balance. The effect of firing temperature of pellets and its porosity on thermal conductivity were determined. The mineralogical changes on firing were investigated. The results were analysed by applying model equation and on the basis of basic sintering parameters to determine effective thermal conductivity at zero porosity with radial heat transfer.

Influence of gaseous sulfur on CO reduction of wustite added with foreign oxides

S. HAYASHI et al.

Dense wustite plates added separately with major gangues in ironmaking were reduced using a thermobalance at 1 173~1 373K with CO-CO_2-COS mixtures to elucidate the cooperative influence of added oxide and gaseous sulfur on the reduction behavior.

In the tests without sulfur, the reduction was extremely retarded by the existence of Al_2O_3 or SiO_2 in wustite mostly by the formation of dense iron in porous or dense wustite (B or C type), while it was fairly enhanced by adding CaO with porous iron (A type).

The sulfur addition of $P_{COS}/P_{CO}=2.2\times10^{-6}$ -2.2×10^{-5} unable to form oxysulfide liquid resulted in less reduction rates relative to those without sulfur. This action of sulfur was added to an influence exerted by Al_2O_3 or CaO. When sulfur and CaO coexisted without any oxysulfides, fibrous iron morphology (F type) was strongly realized. At 1 373K the iron morphology became coarser for pure or MgO-doped wustite by adding COS. Regardless of gangues the reduction rates rised with higher temperatures. For the reduction tests of same samples using sulfur bearing gas, porous iron (A type) was preferred previously in H_2, while the present CO reduction conducted mostly dense iron (C type). This is probably because the former gas has a larger oxygen removal force from sulfur-adsorbed wustite surface than the latter one.

These reduction behavior is discussed focusing a few actions caused by gaseous sulfur.

Steelmaking and Refining

Thermodynamics of molten Fe-Cr-$C_{satd.}$ alloy

Y. KOBAYASHI et al.

The activity of chromium in molten Fe-Cr-$C_{satd.}$ alloy has been measured at temperatures ranging from 1 548 to 1 773K by a chemical equilibrium technique. There is little temperature dependence of the activity of chromium in the region of low chromium contents by weight, and the activity coefficient of chromium decreases as the chromium content increases.

The activity coefficient of chromium in silver, which was needed for the foregoing measurement, was predetermined.

By thermodynamic discussion in combination with the carbon solubility in molten iron-chromium alloys, the expression for the activity coefficient of chromium in Fe-Cr-$C_{satd.}$ alloy has been obtained as a function of chromium content and temperature as follows.

$$\ln\gamma_{Cr(s)} = -2.52+\frac{3\,880}{T}+\left(8.31-\frac{23\,300}{T}\right)X_{Cr}+\left(-4.21+\frac{14\,900}{T}\right)X^2_{Cr}\ (1\,623 \text{ to } 1\,773\text{K})$$

The standard Gibbs energy of mixing of Fe-Cr-$C_{satd.}$ alloy was also estimated using the Gibbs-Duhem relationship, indicating that chromium and manganese behave similarly in terms of affinity for carbon and iron in molten carbon-saturated iron.

Effect of S content on the MnS precipitation in steel with oxide nuclei

M. WAKOH et al.

Manganese sulphide formation experiments were carried out by deoxidizing with various elements and by changing S content to clarify the effect of S content on the MnS precipitation with various kinds of oxide nuclei. The behavior of MnS precipitation on oxide particles in the steel with 1 mass% of Mn was characterized according to S content. When S content was below 100 ppm, a lot of MnS precipitated only on some kinds of oxide. It is effective to use an oxide having high sulphide capacity and low melting temperature for uniform dispersion of fine MnS. On the other hand, when S was above 100 ppm, almost all the oxides worked as the precipitation sites of MnS. In that case, for the MnS dispersion, it is better to select the oxide which tends to disperse finely itself in steel. The average diameter of MnS, calculated by using a mathematical model considering the oxide nuclei nuclei with changing the precipitation ratio according to S content and to the kind of oxides, agrees well with the experimental data.

Casting and Solidification

Application of solidification theory with small-supercooling to morphology of dendritic inclusions in steel

M. IMAGUMBAI et al.

Tip shape of dendritic TypeII manganese-sulfide is analysed based on the supercooling solidification theory which Lipton *et al.* proposed. The theory is derived from the marginal stability of dendrite tip, and needs several physical parameters and constants which are not necessarily known accurately for manganese-sulfide/enriched melt interface. The authors' approach took rough assessment to the figures of physical properties, but the results of calculation give a confidence to a theoretical method of evaluating tip radius of the inclusions.

The analysis of molten steel flow in billet continuous casting mold

Y.-H. HO et al.

In this study, the main objective is to develop a mathematical model to simulate the flow behavior of molten steel in billet continuous casting mold. The results can aid the actual operation in continuous casting process.

In order to understand the flow behavior of molten steel in casting mold, a mathematical model based on SOLA method has been developed to analyze the three dimensional turbulent flow conditions. The flow pattern in the casting mold can be described by the analysis and the effects of submerged nozzle design and operating conditions on the flow behavior can be evaluated. The efficiency rate of nonmetallic inclusion removal can be also estimated.

Forming Processing and Construction

Characteristics of pulsed current bead on plate deposit in flux cored GMAW process

P.K. GHOSH et al.

The influences of pulse parameters, arc voltage and welding speed on the characteristics of weld beads deposited on C-Mn steel plate by flux cored GMAW process have been studied. The pulse parameters are found to affect the microstructure and porosity content of weld

bead and the width of HAZ. The arc voltage, affecting the l_p and l_b, also found to influence the characteristics of weld bead significantly. The porosity content of weld bead and the width and hardness of HAZ are found to have a significant correlationship with a factor, defined as a function of l_p, l_b, f and t_b. The influence of welding speed has been found of usual nature. It is marked that a right selection of pulse parameters can improve the weld quality over that observed in case of continuous current GMAW.

Microstructure

Recrystallization of Ti IF steel investigated with (EBSP)

D.VANDERSCHUEREN et al.

The deformed structure of cold rolled IF steels consists of a large number of α fibre and γ fibre oriented grains and a small number of (110) ⟨110⟩ oriented grains, each with a distinctive grain shape, subgrain structure, hardness and etching appearance. Early nucleation occurs mainly in γ fibre grains and (110) ⟨110⟩ grains. The texture of the early nuclei consists of a γ fibre with a spread towards (221) ⟨110⟩ together with a weak <100>//ND fibre. Numerous nuclei develop within a single deformed grain. Growth competition of these nuclei starts within the borders of the deformed grain. α fibre grains are consumed only after 70% of the material is recrystallised.

Effect of large particles and fine precipitates on recrystallization and transformation behaviour of Ti treated low carbon TiO steel

D.YU et al.

Austenite recrystallization and ferrite transformation behaviour of a Ti treated low carbon TiO steel was studied by uniaxial hot compression in a temperature range of 780 to 1 300°C. The results have been compared to that of a conventional TiN steel. It was found that large oxide particles present in TiO steel have shown ability to stimulate recrystallization nucleation and transformation during deformation but failed to accelerate recrystallization of bulk material because of an insufficient volume fraction of these large particles in the steel. The influence of Ti : N ratio in TiO steel is critical to TiN precipitation behaviour which affects microstructural development during thermomechanical processing. TiN precipitates in TiO steel are coarser in comparison to conventional Ti microalloyed steels thus reducing grain boundary pinning effects. It was also found that recrystallization of ferrite in cold worked TiO and TiN steels was not affected significantly by large particles and fine precipitates but controlled by pearlite size and distribution.

Influence of alloying elements in solution on static recrystallization kinetics of hot deformed steels

S.F.MEDINA et al.

Using torsion tests and applying the back extrapolation method, a study has been made of the influence on static recrystallization kinetics of the most common elements (C, Si, Mn, Mo) in low alloy steels and the most common elements (Ti, V, Nb) in microalloyed steels. In the latter case, this influence is studied only at the temperatures at which these elements are in solution, except for Titanium which was partially precipitated in the form of nitrides. Activation energy is the parameter most sensitive to variations in the chemical composition and an expression has been determined to predict its value as a function of the content of each alloying element. Of the different non precipitate-forming alloys silicon is shown to be the element which most delays recrystallization. Carbon and vanadium in solution have no influence on recrystallization kinetics. It is demonstrated that Nb is the microalloying element which most delays recrystallization.

Static recrystallization modelling of hot deformed steels containing several alloying elements

S.F. MEDINA et al.

Using torsion tests a model has been constructed to predict the recrystallized fraction of deformed austenite in low alloy and microalloyed steels. The model quantifies the influence of the most common elements (C, Si, Mn, Mo) in low alloy steels and the typical elements (Ti, V, Nb) in microalloyed steels in the recrystallized fraction, when they are in solution. Static recrystallization kinetics follow Avrami's law and expressions for the parameter $t_{0.5}$ and for the exponent n are not given. The values predicted by the model are compared with the experimental values, good concordance being obtained between both.

Static recrystallization modelling of hot deformed steels at temperatures below the critical temperature

S.F. MEDINA et al.

Using torsion tests and applying the back extrapolation method a model has been constructed to predict the recrystallized fraction of deformed austenite in Nb, V and Ti microalloyed steels at temperatures below the temperature at which the inhibition of recrystallization commences due to induced precipitation. This temperature, named static recrystallization critical temperature, is modelled as a function of grain size, strain and the solubility temperature. A discussion is made of the importance of being able to predict SRCT in order to effectively apply the model of static recrystallization at temperatures both above and below it. It is demonstrated that Niobium precipitates delay the recrystallization most.

Static recrystallization of Nb and Nb-B steels under continuous cooling conditions

D.Q.BAI et al.

The recrystallization behaviour of nine steels containing various combinations of Mo, Nb and B was investigated under continuous cooling conditions. Hot torsion tests were performed using a 17 pass deformation schedule at strain rates of 0.2 to $10s^{-1}$, and interpass times of 1 to 150 sec. After reheating at 1 250 or 1 200°C, the first deformation was applied at 1 180°C and the last one about 700°C. By plotting mean flow stress vs. $1\,000/T$, the no-recrystallization temperatures (T_{nr}) wer determined, and the effects of chemical composition and deformation conditions were assessed. Separate empirical equations for the T_{nr} were derived from the data for short and long interpass times. These relations describe the influence of chemical composition and of the pass strain, strain rate, and interpass time under continuous cooling conditions. Furthermore, the relationship between the residual strain ε_r or the residual strain ratio λ and the deformation parameters was also established by analyzing the flow curves. This made it possible to specify the recrystallization limit temperatures (RLT) and recrystallization stop temperatures (RST) that apply to each steel and to each combination of rolling conditions.

Modelling the evolution of the microstructure of a Nb steel

J.MAJTA et al.

A mathematical model, for the prediction of the evolution of the microstructure during hot forming of microalloyed steels, is presented. The material behavior is combined with a finite-element model of the deformation. Multi-stage, isothermal compression tests are used for verification. The effect of the interruption between stages of compression on the restoration mechanisms is studied in three-stage tests. The influence of the deformation history on the microstructural development and on the softening mechanisms is also analyzed. The distribution of austenite grain sizes is predicted. The inhomogeneity of the resulting structure is connected to that of the mechanical attributes of the deformed material. The studies show that additional grain refinement can be expected by controlling the recrystallization kinetics and the retained strain.

Physical and Mechanical Properties

Formation of surface texture and anisotropy of shape memory effect in an Fe-Mn-Si alloy

O.MATSUMURA et al.

Formation of surface texture and its influence on shape memory effect in an Fe-Mn-Si alloy have been investigated, using specimens taken from the surface layer and from the central layer of the hot rolled sheet produced

using a low-temperature finishing. It was found that a shear texture with a major component of {001} ⟨110⟩ was formed in the surface layer of the sheet, resulting in a marked anisotropy of shape recovery strain, while a pure metal type rolling texture was formed in the mid-thickness, leading to a less anisotropy. A maximum of shape recovery strain at a given prestrain is obtained for the specimens with tensile axes parallel to the rolling direction(RD) or the transverse direction to the RD in the plane of the surface layer, *i.e.* the specimens with their tensile axes preferentially oriented to ⟨110⟩. This suggests the possibility of improvement in shape memory effect of the whole sheet by a further spreading of the surface texture towards the central layer of the sheet if the rolling process is optimized.