Fundamentals of High Temperature Processes

Rupture phenomena of molten $Na_2O \cdot 2SiO_2$ thin films

T.KURANAGA et al.

A thin film drawn-out technique was developed to investigate the rupture mechanism of molten sodium silicate thin films. The rupture length of molten sodium silicate films was measured as a function of temperature and the drawn-out rate. It was found that the rupture thickness, T, was dependent on the drawn-out rate, v, at high drawn out rate, being proportional to the 2/3rd of v, *i.*e.,

$$T \propto (v)^{2/3}$$

At low drawn-out rate the rupture thickness was found to be independent from v below a critical value v_c.

It was concluded that the rupture at high drawn-out rate was controlled by the external drawn-out rate of the molten slag and the constant rupture thickness at the low drawn-out rate might be determined by the Plateau border suction flow.

Casting and Solidification

Physical and mathematical modelling of continuous casting tundish systems (Review)

D.MAZUMDAR et al.

Considerable efforts have been made in academia and industry over the last two decades to fully exploit and enhance the metallurgical performance of continuous casting tundish systems. Towards these goals, numerous physical and mathematical modelling studies embodying both industrial and water model tundishes have been carried out and reported in the literature. Based on an extensive literature search, we now present a summary, discussion and analysis of these. For the sake of convenience and clarity of presentation, the studies have been categorised into three major groups: (1) physical modelling (2) mathematical modelling and (3) combined physical and mathematical modelling. In each of these categories, a great number of publications on various aspects of tundish metallurgy, such as, modelling criteria, turbulent fluid flow, residence time distributions (RTD), inclusion transport and separation, heat loss and temperature drop, grade transition and intermixing, *etc.* have been reported. These works have lead to considerable improvements in our understanding of the various transport processes (*viz*, RTD, inclusion float out, thermal energy transport, *etc.*) associated with tundish operations. Comprehensive and sufficiently reliable mathematical models are also currently available and these also allow one to carry out full scale predictions and useful engineering design and process calculations. None the less, certain obscurities and uncertainties remain. These are reviewed together with suggestions of areas where further research is needed.

Behavior of fine bubbles in front of the solidifying interface

Z.WANG et al.

In front of the solidifying interface, the solidifying boundary layer plays an important role in determining whether foreign particles could be engulfed or not by the solidifying interface. In this study, we have investigated how the boundary layer influences the behavior of the foreign particles by directly observing the behavior of fine bubbles in front of a vertical solidifying interface of the water solution. In the case of surfactant ($C_8H_{17}SO_3Na$) water solution, bubbles in the vicinity of the solidifying interface were found to move horizontally toward the solidifying interface, and then were engulfed by it. However, this phenomenon was not observed in the case of NaCl water solution.

Analysis indicated that inside the boundary layer with a surfactant concentration gradient, a surface tension gradient around the interface of the bubble and the solution was formed. We have concluded that the surface tension gradient generates a driving force on the bubble, causing the bubble to move towards the solidifying interface. Experimental results were found to be well in accord with theoretical analysis.

Rayleigh–Taylor instability in the process of clad steel slab casting with level DC magnetic field

M.ZEZE et al.

The effect of density difference between two kind of molten steels on the separation of chemical composition in the continuous casting process for clad steel slabs has been studied by experiment with a pilot caster. When the density of upper pool is lower than that of lower pool, the density difference stabilizes the separation of chemical composition. In the converse case, the density difference causes Rayleigh–Taylor instability which destabilizes the interface between the double layer inviscid fluid. As a result, the density difference promotes the mixing of chemical composition between the upper and lower pools. However, the stability analysis taking account of magnetohydromagnetic effect shows the mixing between the upper and lower pools can be suppressed by DC magnetic field. This effect of the magnetic field is classified into the term of magnetic pressure and the term of magnetic field gradient.

Welding and Joining

Effects of transverse oscillation on tensile properties of mild steel weldments

S.P.TEWARI

In this paper an attempt has been made to study the effects of frequency and amplitude of transverse oscillation on yield strength, ultimate tensile strength, breaking strength and percentage of elongation of weldments. The weldments were prepared under different oscillatory conditions. The frequency and amplitude of transverse oscillations during experimentation were varied from 0 to 400 Hz and 0 to 40 μm respectively.

The tensile properties of the weldments prepared under oscillatory conditions are improved whereas the percentage of elongation reduced when compared with the stationary welded test specimens. It has been observed that increase in frequency of transverse oscillation results in the improved tensile of the weldments except the percentage of elongation which decreases with increase in frequency of oscillation. At 80 Hz frequency higher amplitude show greater value of tensile strength than lower amplitude. But at higher frequencies (300 Hz and 400 Hz) lower amplitudes show a significant increase in tensile strength value than higher amplitudes. The increase in tensile strength under oscillatory conditon is due to the grain refinement which is caused by dendrite fragmentation and grain detachment mechanism.

Transformations and Microstructures

Effect of test variables on apparent activation energy for hot working and critical recrystallization temperature of Nb-microalloyed steel

N.RADOVIĆ et al.

Two-stage linear $\ln[\sinh(\alpha\sigma)]$ *vs.* $1/T$ relations indicative of double Q_{HW} behavior, are obtained from anisothermal multipass flow curves generated by testing Nb/Ti microalloyed steel in torsion (in the range 1250–800°C), except for the case of the high cooling rate–short interpass time tests, which gave rise to single-stage plots, indicative of single Q_{HW} behavior. Above the T_{nr}, the Q^U_{HW} (apparent activation energy for hot working corresponding to the upper temperature range) is little affected by test variables (interpass time and cooling rate) and type of deformation (isothermal continuous and anisothermal multipass deformation give virtually equivalent Q^U_{HW} , values above the T_{nr}). However, below the T_{nr}, the Q^L_{HW}, corresponding to the lower temperature range, becomes sensitive to test variables, and may show considerable deviation from Q^L_{HW} obtained in continuous tests. Therefore, the temperature dependence of the flow stress, below the T_{nr}, relevant to a multipass hot working operation, can be well described only by the Q^L_{HW} obtained from the multipass flow curves, because it is interpass time dependent. The interpass time dependence of both the Q^L_{HW} and the T_{nr} can be divided into three regions. Within the short interpass time region (1.8 to 10 sec), the two parameters show opposite trends, while beyond 10 sec they correlate well. Within the 1.8 to 10 sec region the T_{nr} is assumed to be controlled by Nb in solid solution, while the Q^L_{HW} is controlled by both solute and precipitation effect. Beyond 10 sec precipitation is the only controlling mechanism. In addition to the T_{nr} derived from Mean Flow Stress (MFS) and $\ln[\sinh(\alpha\sigma)]$ *vs.* $1/T$ plots, the recrystallization limit, T_{rl}, which correlates well with both T_{nr}'s, and the recrystallization stop, T_{rs}, temperatures are derived from % Fractional Softening (FS) *vs.* $1/T$ plots.

Influence of the prior austenite microstructure on the transformation products obtained for C–Mn–Nb steels after continuous cooling

R.BENGOCHEA et al.

In the present work, the ferrite grain sizes after transformation from non-deformed (recrystallized) and work-hardened austenite have been considered.

Two C–Mn–Nb steels have been deformed by multi-pass torsion tests carried out at temperatures, both above and below the determined T_{nr} (non recrystallization temperatures) for these steels. The influence of the prior austenite grain size, the retained strain and the cooling rate on the final ferrite microstructure has been analysed. Austenite grain sizes varying from 28 to 125 μm with retained strains ranging from 0 (non-deformed austenite) to 2 and cooling rates of 1 and 5 s^{-1} have been considered. It has been observed that higher cooling rates tend to produce acicular microstructures, and that this effect is enhanced at the lower retained strains. It has been shown that the reduction of austenite grain size and an increase of retained strain, provide a higher density of nucleation sites, which leads to a refinement of the ferrite. A similar effect is produced by increasing the cooling rate from 1 to 5 s^{-1}.

Grain refinement under multiple warm deformation in 304 type austenitic stainless steel

A.BELYAKOV et al.

The dynamic process of fine grain evolution as well as deformation behaviour under warm working conditions was studied in compression of a 304 type austenitic stainless. Multiple compression tests were carried out at a strain rate of 10^{-3} s^{-1} to produce high cumulative strains, with changing of the loading direction in 90° and decreasing temperature from 1223 to 873K (0.7–0.5 T_m) in each pass. The steel exhibits two types of deformation behaviours with different mechanical and structural characteristics. In the deformation region where flow stresses are below about 400 MPa, conventional dynamic recrystallization takes place accompanied mainly by bulging of serrated grain boundaries. The dynamic grain size evolved can be related to the high temperature flow stress through a power law function with a grain size exponent of −0.72. On the other hand, in the region of higher stresses above 400 MPa the flow stresses show small strain rate and temperature dependence, and so it is suggested to be in an athermal deformation region. The stress–strain curves show a steady state like flow without any strain softening, while the multiple deformation to high cumulative strains brings about the evolution of fine grained structures with grain sizes less than one micron. The relationship between the warm temperature flow stresses and the grain sizes evolved also can be expressed by a unique power law function of grain size with an exponent of −0.42. The interrelations between the mechanisms of plastic deformation and microstructure evolution at warm and high temperatures are analysed in detail and also the multiple compression method for obtaining ultra fine grained structure is discussed as a simple thermo-mechanical processing.

Grain boundary nucleation of proeutectoid ferrite in an Fe–C–Ni alloy

M.ENOMOTO et al.

The nucleation kinetics of proeutectoid ferrite at austenite grain boundaries were studied in an Fe–C–Ni alloy by observing ferrite particles on fracture facets along prior austenite grain boundaries. Whereas a large scatter in the ferrite particle number was observed among grain boundary facets, the average particle number appeared to increase with isothermal holding time. The particle number measured on the polished surface of the specimens applying Schwartz–Saltykov analysis also increased with holding time. Diffusion-controlled growth of a ferrite nucleus was simulated incorporating Gibbs-Thomson capillary effect to indicate that the time for a nucleus to grow to a detectable size was insignificantly small. These results seem to indicate that ferrite nucleation occurred in a sizable time range and continuous nucleation, rather than site saturation (instantaneous nucleation), may describe better ferrite nucleation kinetics at the temperatures of measurement. The difference in the ferrite particle number between the two methods of measurement is discussed in terms of the possible omission of small particles and non-sphericity of ferrite particles *etc*.

Physical Properties

Effect of oxide shape on magnetic properties of semiprocessed nonoriented electrical steel sheets

Y.KUROSAKI et al.

The effect of oxide shape on magnetic properties of semiprocessed nonoriented electrical steel sheets produced by single reduction cold rolling process was studied. When oxides in steel sheets were elongated inclusions which were prescribed as B type by JIS, the oxides inhibited grain growth during consumer annealing and average grain size became small. As a result, core loss was bad. When oxides were spherical inclusions which were prescribed as C type by JIS, the oxides did not inhibit grain growth and average grain size became large. As a result, core loss was good. Oxide composition affected the shape remarkably. The degree of elongation of oxides had much to do with the viscosity during hot rolling. The viscosity of oxides containing less MnO and much SiO_2 was high, and the degree of elongation was small. Consequently, these oxides became spherical C type inclusions.