Fundamentals of High Temperature Processes

Thermodynamic analysis of binary and ternary silicate systems by a structural model

A.R.-SERRANO et al.

A critical evaluation of the thermodynamic properties as well as the phase diagrams for the systems $MgO–SiO_2$ and $FeO–SiO_2$ is performed with a structural model and for the systems MnO–MgO, FeO–MnO and FeO–MgO through the regular solution model.

The structural model for binary silicate melts is now extended to ternary systems. It is shown that, for systems SiO_2–AO–BO, random mixing of cations A^{2+} and B^{2+} occurs when the oxides AO and BO behave in a similar way with silicate. If the AO–SiO_2 and BO–SiO_2 binary systems exhibit similar thermodynamic behavior, that is comparable free energies of mixing, the properties of the ternary SiO_2–AO–BO can be extrapolated from those binary systems in a straightforward fashion. This condition is found in simple silicates such as SiO_2–MnO–MgO, SiO_2–FeO–MnO and SiO_2–FeO–MgO systems where the activities and liquidus temperatures calculated solely from data on the binary sub-systems are in good agreement with measured ternary data.

Numerical analysis of nitrogen absorption rate accompanied with Marangoni convection in the molten iron under non-inductive stirring condition

Z.JUN et al.

Numerical analysis was carried out to investigate nitrogen absorption rate accompanied with Marangoni convection due to surface tension gradient on the free surface of liquid iron by using the commercial CFD software package. Good agreements between the experimental values and the calculated results were attained with various oxygen contents. It could be deduced that the Marangoni convection occurred continuously until the liquid iron is saturated with nitrogen, since the gradient of the nitrogen concentration could be maintained on the free surface of liquid iron owing to flow of the liquid iron. The decrease in nitrogen absorption rate with increasing oxygen content under non-inductive stirring condition could be attributed to the dwindling of convection in liquid iron and the effective diffusion coefficient as the liquid iron flow changes from the turbulent to the laminar flow.

Steelmaking and Refining

Water model experiments on mixing phenomena in a VOD ladle

K.KRISHNAKUMAR et al.

Mixing phenomena in a VOD ladle were characterized by a watermodel simulation from the determination of mixing times by electrical conductivity measurements. Two mixing times defined for two degrees of mixing, *viz.*, t_{95} (95% mixing) and t_{99} (99% mixing) were identified for each experiment. Various operating conditions as well as different placements of bottom nozzle with and without a top jet were simulated. Irrespective of whether the top blow is present or not, mixing rates were found to be increasing considerably as the nozzle position is moved from the center to the mid-radius position. The presence of a top jet, as in a VOD ladle, was found to weaken mixing for both a coaxial and non coaxial placement of the lance with the bubble plume. The results of watermodel experiments have been used to construct a simple two-tank model of mixing inside the actual ladle, in which the parameters are obtained as functions of process variables.

Agglomeration and floatation of alumina clusters in molten steel

H.TOZAWA et al.

An equation for the floating velocity of cluster-shaped alumina inclusions which considers changes in average density was derived by quantifying the size and density of alumina clusters using fractal theory. The results obtained showed that the dependency of the floating velocity on the cluster diameter is smaller than in the conventional equations, which assume that clusters have a uniform average density. In particular, the floating velocity of clusters 100 μm and over is considerably smaller than the conventional floating velocity.

A model of the coalescence of cluster-shaped inclusions was also constructed, and the behavior of alumina clusters in molten steel in the tundish of an actual continuous casting machine was analyzed considering floating characteristics and agglomeration. The calculated results showed good agreement with the results measured in the actual machine, demonstrating that it is possible to simulate the coalescence and floating separation of cluster inclusions in molten steel with this model.

Casting and Solidification

A fully coupled analysis of fluid flow, heat transfer and stress in continuous round billet casting

J.-E.LEE et al.

The thermal and vectorial fields in the strand and the temperature distribution in the mold were analyzed with a finite difference method (FDM) considering the effects of turbulence and natural convection of molten steel. The thermo-elasto-plastic behaviors of the strand and the mold were analyzed with a finite element method (FEM) taking into account the ferrostatic pressure due to the gravity force and the mechanical behaviors of the strand in liquid phase, mushy zone and δ/γ phase. The microsegregation of solute elements in steel was assessed to determine some characteristic temperatures and solid, δ-Fe and γ-Fe fractions in the mushy zone. The heat transfer coefficient between the solidifying shell and the mold wall was iteratively determined with the coupled analysis of the fluid flow-heat transfer analysis by the FDM and the thermo-elasto-plastic stress analysis by the FEM. With the above procedure, the mathematical model has been developed to predict the possibility of cracks in the strand, originated from the interdendritic liquid film in the mushy zone, through the fully coupled analysis of fluid flow, heat transfer and stress in the continuously cast round billet. The calculated mold temperature and heat flux at various casting speeds show good agreements with the reported experimental observations.

A finite element model for 2-dimensional slice of cast strand

H.N.HAN et al.

A two-dimensional thermo-elasto-plastic finite element model for the analysis of thermo-mechanical behavior of strand in continuous casting process has been developed. The model incorporates the effect of microsegregation of solute elements on hot tears using a thermo-mechanical model of mushy zone and δ and γ phases. A finite element technique for the liquid region of the slice of strand, which can take the ferrostatic pressure due to gravity force into account, was proposed. The model successfully analyzed the thermo-mechanical behavior of the solidifying shell of slab in the mold during the solidification. The calculated results, such as the deformed geometries, the temperature history, the stress distribution and the formation of air gap between solidifying shell and mold in the continuous casting process of slab, were obtained. These were compared with the reported observations.

Numerical and modeling analysis of fluid flow and heat transfer of liquid steel in a tundish with different flow control devices

R.D.MORALES et al.

Fluid flow and heat transfer of liquid steel in a two-strand tundish of a slab caster were analyzed using water modeling and numerical techniques. Three cases were considered: A bare tundish, a tundish equipped with a pair of weirs and a pair of baffles (arrangement W&B) and a tundish equipped with a turbulence inhibitor and a pair of baffles (arrangement TI&B). The water modeling, under isothermal conditions, indicated the existence of a strong bypass-flow for the bare tundish and the W&B arrangement while the TI&B arrangement reported a longer minimum residence time and higher plug flow characteristics. Numerical results verified the trend mentioned with the water model. The numerical study showed also that cold and hot steel affected considerably the flow patterns of steel due to the existence of buoyancy forces. In the case of a step-input of cold steel, bypass-flow was intensified for the bare tundish and the tundish with a W&B arrangement. When a step input of hot steel is introduced into the system buoyancy forces make the steel to flow preferentially near the free surface.

The tundish with a TI&B arrangement showed the best flow characteristics with not splashing and negligible turbulence. This arrangement shows a slower response to thermal disturbs coming from the input making the tundish a less exposed reactor to the temperature changes and the consequent changes in flow patterns usually found in real casting operations.

Effect of coiling operation on strip quality in twin-roll casting process

N.M.ZAPUSKALOV

Rapid solidification in the twin-roll casting process allows the production of thin strip with a unique combination of properties, directly from the melt. However, the production of the thin strip without any intermediate technological processing, is accompanied by strong demands on quality of the as-cast strip and requires full understanding of all aspects of twin-roll casting technology.

The present study was aimed at an experimental analysis of the influence of continuous coiling in the twin-roll casting process on structure, properties and the shape of as-cast high silicon electrical steel strip. It was found that solidification, cooling and plastic deformation produce high residual stress heterogeneity in the as-cast strip which exists in a non-equilibrium state. When the compressive residual stress, attains a critical value the strip loses its flatness and waviness of a sinusoidal shape appears on the surface in the casting direction. When the tensile residual stress reaches the yield strength of the casting materials, cracks may be appear in the strip.

The use of continuous coiling at elevated temperatures and with the as-cast strip under tension, leads to a change in structure, properties, geometry and shape of the as-cast strip. The structure and properties can be effectively controlled by regulating the temperature of the coiled strip and the shape can be controlled by regulation of the strip tension.

The use of optimal temperature and strip tension during the continuous coiling operation are effective control strategies for stabilising structure, properties, and shape of the as-cast strip, reducing the residual stresses in the strip and improving its quality.

Instrumentation and Control System

Particle imaging velocimetry measurement of particle number rate and velocity for falling particles

X.SONG et al.

The number of particles passing through the whole field of interest in a unit time, referred to as the articles particle number rate, cannot be measured accurately and easily by the conventional methods when the number density of particles is high. However, there are many demands for whole field measurement of the particle number rate in various industrial processes. The purpose of the present investigation is to develop a new method for measuring the particle number rate by introducing PIV (Particle Imaging Velocimetry). In the present work, particles coming out of a hopper, and then falling in air or water were treated. Images of the falling particles were taken by a high speed video camera. Particle velocities were measured by the PIV based on the Binary Image Cross-Correlation Method (BICC), and the particle number rate crossing a plane could be computed from the mean velocity of particles and the number of particles in the image. The performance of the present method for measuring the particle number rate was evaluated by numerical simulations and experiments. The experimental results showed that the particle number rate of a cloud of particles could be measured with high accuracy by the newly developed methods. The measurement precision of the particle number rate depends on the number of sampling video frames. Several seconds of video frames can yield sufficient precision of the particle number rate. The present research can be applied to on-line measurement of particles in many industrial fields.

Microstructure

Metallurgical features of steel plates with ultra fine grains in surface layers and their formation mechanism

H.MABUCHI et al.

Steel plates with heavy gauge, which are mainly applied to large steel structures, are consequently subject to improved low-temperature toughness as well as weldability by the application of general TMCPs. The advanced TMCP has been developed so as to industrially manufacture SUF (Surface layers with Ultra Fine grains) steel plates with high crack arrestability in avoiding unexpected catastrophic damage of large steel structures. The advanced TMCP is characterized by the accelerated cooling in the midst of rolling followed by controlled rolling in the reheating process, while the general TMCPs are described by the controlled rolling in air cooling followed by various types of accelerated cooling after the rolling. Mechanical properties governed by metallurgical features of surface layers are extremely improved by the adoption of SUF steel plates. In addition, the formation mechanism of ultra fine grains in the surface layers of SUF steel plates are discussed from metallographic viewpoints.

Physical and Mechanical Properties

The influence of microstructural morphology and prestrain on fatigue crack propagation of dual-phase steels in the near-threshold region

K.NAKAJIMA et al.

The influence of microstructure and prestrain on fatigue crack propagation in the near threshold region was studied for dual-phase steels with different microstructural morphologies. The material with martensite phases dispersed in ferrite matrix exhibited a higher nominal stress intensity range and a lower crack propagation rate than those of material with a continuous martensite phase around ferrite grains. Prestrain prior to fatigue testing resulted in a decrease of nominal stress intensity range in both materials. However there was a slight difference among all the materials in the effective stress intensity range. The microstructural morphology and prestrain exerted a great influence on crack path and that caused a large difference in crack closure. A quantitative correlation existed between crack closure level and surface roughness of fatigue fracture.

The mechanical properties of a low alloyed Austempered Ductile Iron in the upper ausferrite region

D.C.WEN et al.

Microstructural observations, X-ray diffraction testing and measurements of mechanical properties were used to study the characteristics of austempering and the influence of tempered martensite on mechanical properties as a function of austempering time at 400°C after austenitising at 900°C for a 0.77%Cu–0.5%Ni ductile iron. The austempering times were derived from a resistivity curve measured by a vacuum heat treatment system. The experimental results show that the resistivity change curve could be used effectively for selecting the isothermal holding times of austempering treatment, with all the mechanical properties of ADI austempering at times corresponding to the processing window defined by the electrical resistance measurement satisfying the standard requirement. The formation of martensite in austempering reduced the mechanical properties of ADI but these properties could be increased by a treatment tempering at 200°C after cooling and to obtain more ductility and toughness as compared with that undergoing single heat treatment. This increase also extended the effective austempering time interval of ADI over which the ASTM standards were satisfied.

Analysis and prediction of earing behavior in cup drawing of bcc metals by use of crystallographic method

S.-Y.LI et al.

Earing behavior in cup drawing of bcc metals has been investigated by use of a modified Tucker method using simple $\{110\}\langle 111\rangle$ slip and complex $\{110\}+\{112\}\langle 111\rangle$ slip respectively. The influence of stress state on earing behavior was analyzed by varying the ratio of radial stress to circumferential stress in the flange of the blank. The results demonstrated that, the earing characteristics of the main ideal orientations in bcc metal sheets could be well predicted by the present method. The earing behavior is not sensitive to the slip mode employed in the calculation. It was shown that the variation of stress ratio had no obvious influence on the earing profiles, and that the variation of earing extent with the stress ratio could be very different for various orientations. Based on the predictions and the experimental observations, the discrepancies existed in the literature for the earing tendencies of the main texture fibers were analyzed and clarified. It was shown that the earing tendencies of the same ideal orientations in bcc metals were not necessarily the same as those exhibited in fcc metals. The present method in conjunction with $\{110\}\langle 111\rangle$ slip and stress ratio of 1 was satisfactorily applied to predict the six-ear results for two steels.