Fundamentals of High Temperature Processes

3D numerical analysis on electromagnetic and fluid dynamic phenomena in a soft contact electromagnetic slab caster

P.R.CHA et al.

A three dimensional mathematical model for fluid flow in the mold of the soft contact EMC (Electro-Magnetic Casting) with the bifurcated SEN (Submerged Entry Nozzle) was developed. FEM (Finite Element Method) for the calculation of electromagnetic field and FVM (Finite Volume Method) with BFC (Body Fitted Coordinate) for the fluid flow considering the complex geometry of the electromagnetic mold and the irregular meniscus shape of the melt were used.

This mathematical model was applied to an experimental EMC process with 200mm×50 mm rectangular cold crucible type mold and the tin melts as the slab. In this study, a mathematical model which can analyze the EMC system was developed and a characteristic three dimensional electromagnetic phenomena and fluid flow of slab EMC with the bifurcated SEN were investigated. Several typical phenomena such as the concentration of electromagnetic force on the surface of the molten metal, the increase of flow velocity on the meniscus were found.

Physical characteristics of a horizontally injected gas jet and turbulent flow in metallurgical vessels

M.ZHU et al.

Besides the bottom vertical gas blowing, horizontal gas injection through both a nozzle fitted at the sidewall and a submerged lance has a wide application to metallurgical processes for converting and refining purposes. Based on analysis of the behavior of a gas jet injected horizontally into liquid, a plume model was presented to predict the volume fraction of gas in the two-phase region, and a mathematical model was developed to predict three-dimensional turbulent flow and mixing process. In the present work, three types of horizontal injection were taken into account and the optimization of gas injection through a submerged lance with one horizontal tuyere was carried out. The results show that the maximum volume fraction of gas along the upward jet trajectory decreases by about 50 % compared with the bottom vertical blowing, while the half-value radius of maximum volume fraction of gas increases about two times; the distributions of velocity and turbulent kinetic energy are relatively uniform and big azimuthal component of velocity is produced in the bath; horizontal injection has an advantage of rapid mixing over bottom injection and the injection by a submerged lance with one horizontal tuyere shows the shortest mixing; basically, the presented models are capable of describing the phenomena occurring in the bath with horizontal gas injection.

Numerical analysis of transient flow in a water bath contained in a cylindrical vessel suddenly set in rotation

S.YOKOYA et al.

Transient flow in a water bath contained in a cylindrical vessel, being initially at rest and then suddenly set in rotation, was investigated experimentally and numerically using the FLUENT computer code. This flow field is a model of molten metal flow in the rotating reactor of materials processing systems. Two different boundary conditions were imposed on the bath surface: solid wall and free surface. Because the Ekman boundary layer developing on the bottom wall (and on the top wall in the former case) became unstable, the flow in the bath was neither purely laminar nor fully turbulent in the course of flow establishment. As one of simplified calculation methods, the kinematic viscosity of liquid was increased artificially in the laminar calculation so that the calculated transient velocity profiles best fitted the presently measured velocity profiles in the water bath with the top wall. This method could approximate the transient velocity profiles in the bath with free surface as well. The flow establishment time in the presence of the top wall became half the value for the free surface.

Ironmaking and Reduction

Slag-metal separation in the blast furnace trough

R.J.FRUEHAN et al.

It is important to reduce metal losses associated with the slag in the blast furnace runner. Insufficient separation gives rise to technological problems in the subsequent processing of hot metal and slag in addition to the losses themselves. By using a water-oil physical model of the blast furnace trough, the flow behavior and the separation efficiency in the trough were investigated. A series of experiments was carried out by changing the process variables such as flow rate of liquids, properties of oil (slag), and geometrical design of the trough. The results indicate that, at constant physical properties, the flow velocity in the upper stream of the trough is the predominant factor in determining the amount of metal carried over with slag. Oil (slag) viscosity was also found to be an important contributor in the separation efficiency. The mechanism for the slag entrainment into the metal phase was also investigated. The results indicate that the amount of slag (oil) entrained into metal (water) is mainly determined by the force balance between inertial force in the metal stream, the viscous force, and the gravity force in the upper stream. Because of this mechanism, the oil entrainment ratio decreased sharply with oil volume while the effect of total flow rate, water and oil, was comparatively small. In order to extend the results obtained by this modeling study to the actual system, a technique of dimensional analysis was also employed. As a result, dimensionless group correlations which can describe the separation efficiency as a function of process variables and dimensions of the trough were derived.

Casting and Solidification

Thermal resistance at the interface between mold flux film and mold for continuous casting of steels

J.CHO et al.

Heat transfer from solidifying shell to mold near the meniscus plays an important role for the formation of surface cracks on continuously cast steel products. The heat transfer is influenced substantially by the thermal resistance at the interface between mold flux film and copper mold. Accordingly, a model system consisting of steel shell/mold flux film/copper mold is built to simulate the heat transfer near the meniscus in the mold for continuous casting, and the thermal resistance is determined by measuring temperature gradient in the copper mold in the simulator. The interfacial thermal resistance increases with increasing flux film thickness in contrast to previous observation by others who assumed that the interfacial thermal resistance is constant for different flux film thickness. The interfacial thermal resistance is found to be about 50 % of overall thermal resistance for the heat transfer. Mold fluxes for medium carbon steel with higher crystallization temperatures show lower heat flux than those for low carbon steel not due to reduced radiative heat transfer but due to higher interfacial thermal resistance at the same flux film thickness. This arises from the difference in crystallizing behavior such as growth rate of crystalline layer between the two fluxes.

Specification framework for control of the secondary cooling zone in continuous casting

F.R.C.CALZOLARI et al.

A model describing heat transfer in the secondary cooling zone (SCZ) of a continuous caster is derived. In order to reduce the defects arising from improper cooling in the SCZ of a continuous caster, a simple open-loop control strategy is proposed and evaluated. This means that with the aid of an equivalent numerical model of the SCZ, the heat transfer coefficients are found which deliver an ideal or near-ideal temperature profile along the midface of the strand. The temperature profile is specified by the user, and strongly depends on characteristics of the steel and physical constraints of the water cooling system of the continuous caster. Two examples highlighting the open-loop control approach are shown for a low carbon 14cm×14cm billet caster. Simu-

lations show that a temperature profile can be achieved with open-loop control that differs only slightly from the specified temperature profile.

Casting speed, rollers and clogged sprays are the main disturbances that can cause the temperature profile to deviate from ideal. The influence of these disturbances is shown.

Eutectic growth of unidirectionally solidified Fe-Cr-Ni alloy

T.OKANE et al.

In this report, transition of solidified phases in unidirectionally solidified Fe-Cr-Ni alloys was investigated in low growth rate range using Bridgman type furnace. The ferrite-austenite eutectic growth was confirmed under low growth rate condition like a plane front growth of ferrite single phases. The transition velocity between eutectic and ferrite cell growth had a good agreement with the result of calculation based on the phase selection criterion and the interface temperature calculation for ferrite, austenite and eutectic phases. These results show that the phase prediction by calculating interface temperature can be applied not only to competitive growth between single phases like peritectic systems, but also to eutectic systems. Furthermore, under the condition of eutectic coupled growth to be occurred in steady state, the changes of solidified phases and their morphologies in the initial transient are also discussed.

Control of early solidification in continuous casting by horizontal oscillation in synchronization with vertical oscillation of the mold

S.ITOYAMA et al.

A new method of mold oscillation for continuous casting termed "horizontal oscillation" was developed to reduce the depth of oscillation marks without increasing the possibility of breakout. In this method, the wide faces of the mold oscillate horizontally in synchronization with conventional vertical oscillation. Oscillation marks on slabs of SUS304 cast with a pilot continuous caster were examined under various conditions of mold oscillation. Horizontal oscillation successfully reduced the depth of oscillation marks and surface segregation at oscillation marks, and was extremely effective when the wide face of the mold was expanded against the solidified shell during positive strip time. Experiments with an actual machine reproduced these effects of horizontal oscillation. A numerical analysis of the deformation of the solidified shell during one cycle of vertical oscillation was performed to study the effect of horizontal oscillation on the control of early solidification near the meniscus. Friction force acting on the shell near meniscus was also discussed to explain the reduction in the surface segregation.

Surface Science and Technology

Partial substitution of chromate by borate for cooling water inhibition

A.BAHADUR et al.

Chromate is an effective and versatile inhibitor for industrial cooling water systems. Due to its toxicity, borate is added systematically to substitute chromate from 100 to 1 % and tested as inhibitor for a mild steel, using radioactive tracer technique.

The amount of chromium in the film thickness of the inhibitor formed on the specimens is found to increase as borate concentration is increased up to 40 % and decreases thereafter. The protection is obtained at 303 K at least up to 6 h. By reducing chromate from 100 to 60 %, the Cr content in the protective film is found to double in 2-4 h, which shows the synergistic effect of the inhibitor formulation as compared to that of chromate alone.

Microstructure

Work-hardening behavior and evolution of dislocation-microstructures in high-nitrogen bearing austenitic steels

S.KUBOTA et al.

Microstructural evolution during deformation at room temperature has been studied by means of transmission electron microscopy to make clear the reason for high work-hardening in high-nitrogen bearing austenitic steels. Tension tests were carried out at room temperature using three SUS 316L type steels bearing 0.02 to 0.56 mass% nitrogen and 18Mn-18Cr (retaining ring) type steels bearing 0.51 to 0.84 mass% nitrogen. It is found that both yield strength and work hardening increase with increasing nitrogen concentration. In high-nitrogen bearing steels, planar dislocation-arrays are formed in the beginning of deformation, frequently showing multi-dipoles. Then, they overlap to make dislocation walls and at the same time such dislocation-arrays or walls are pinned each other presumably by operation of Lomer-Cottrell reaction at their intersections. The dislocation-wall is expected to play a role similar to grain boundary for further deformation. Microstructure observed in a heavily deformed specimen looks like fine octahedral grid-structure. Thus, dislocation density in a plastically deformed specimen becomes much higher in high-nitrogen bearing steels than in a low-nitrogen bearing steel in which dislocation-cell structure is evolved.

Effect of cooling rates and compressive deformation of austenite on bainitic transformation and microstructure for plastic die AISI P20 steel

D.LIU et al.

In order to reduce both manufacturing process and manufacturing cost, a thermomechanical process for plastic die AISI P20 steel has been developed. The P20 steel treated by the thermomechanical process can be used to manufacture plastic dies directly without any subsequent heat treatments. In the present work, the dependence of microstructure upon cooling rate and deformation condition has been investigated for P20 steel with the aim of optimizing the thermomechanical process. The results show that the hardness decreases and eventually reaches a plateau, meanwhile the microstructure changes from sheaf-like bainite to granular bainite with decreasing the cooling rate in both of the recrystallized and unrecrystallized austenite. Austenite deformed at 850°C exhibited mechanical stabilization against sheaf-like bainite transformation duri ng continuous cooling, resulting in the microstructure refinement and higher hardness in P20 steel.

Fast penetration of Cu in Ni of Cu/Ni/Cu diffusion couples due to diffusion induced recrystallization

M.MORIYAMA et al.

Rapid penetration of Cu in Ni owing to diffusion induced recrystallization (DIR) in the Ni(Cu) system was experimentally examined using the Cu/Ni/Cu diffusion couples consisting of pure Cu single crystals and a pure Ni polycrystalline specimen annealed at 923 and 1 023 K in previous studies. The exper imental results have been theoretically analyzed to find a new criterion for the occurrence of DIR in the present study. According to the experimental results, the thickness l of the DIR region in the Ni phase increases in proportion to the square root of the annealing time t. Thus, if we define the parameter D^h as the hypothetical diffusion coefficient which gives the overall penetration rate of Cu across the DIR region, the thickness l is described as a function of the annealing time t by the equation $l=2\sqrt{D^h t}$. The temperature dependence of D^h has been obtained from the experimental results and then compared with that of the volume diffusion coefficient D^v of Cu in Ni. From the comparison, it is concluded that the ratio D^h/D^v should be greater than thirty in order for DIR to take place in the Ni(Cu) system.

New Materials and New Processes

Estimation of the γ and γ' lattice parameters in nickel-base superalloys using neural network analysis

S.YOSHITAKE et al.

The lattice constants of the γ and γ' phases of nickel base superalloys have been modelled using a neural network within a Bayesian framework. The analysis is based on datasets compiled from new experiments and the published literature, the parameters being expressed as a non-linear function of some eighteen variables which include the chemical composi-

tion and temperature. The analysis permits the estimation of error bars whose magnitude depends on their position in the input space. Of the many models possible, a "committee of models" is found to give the most reliable estimate. The method is demonstrated to be consistent with known metallurgical trends and has been applied towards the study of some experimental alloys.