（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Fundamentals of High Temperature Processes

Mathematical model of over-micron and nano-scale powders: accumulation in a coke fixed-bed filter

M. DE AVILA RIBAS et al.

The advances in Electric Arc Furnace (EAF) dust treatment have been slowed down by high treatment costs and the large amount of residue to be processed and disposed. A process of direct separation and recovery of iron and zinc is now under development, which adds environmental and economical perspectives to the EAF dust treatment process. In this process, a coke bed filter can be directly connected to an EAF, collecting metallic iron and slag components, whereas the gas containing zinc and lead vapors flows to a zinc condenser. It results in zero amount of dust liberated to the environment. A two dimensional, axisymmetric and steady state mathematical model describing a coke fixed-bed filter is developed. The model solves coupled equations for gas-powder flow and is specifically applied in the investigation of over-micron and nano-scale powders (similar to EAF dust particle size) collection behavior. The theoretical model results are compared with the cold model experimental results, in which both injection of glass (over-micron) and silica (nano-scale) powders are considered. Microscopic observations and analysis are performed in order to describe better the injected powder behavior through the filter. EAF dust samples morphology is characterized as agglomerates of small particles. Its particle size distribution is obtained by the combination of leaching treatment and image analysis. Calculated results show that the powders particle size distribution has a direct effect in the static hold up. The model has been validated by its enough agreement for static hold up and pressure drop with experimental data from cold model experiments.

(cf. *ISIJ Int.*, **45** (2005), 303)

Density of liquid IF steel containing Ti

L.ZHONG et al.

Density of liquid IF Steel containing Ti was measured with the modified sessile drop method at a temperature range from 1530 to 1610°C. Densities of pure molten Fe measured at a temperature range between 1550°C and 1600°C were quite close to those obtained by Saito *et al.*, but a little lower than their results at temperature higher than 1600°C. Thermal expansion coefficient of molten IF steel containing Ti increased linearly with an increase in titanium content. The density of the liquid IF steel was described as a function of the temperature and Ti content as follows:

$$\rho = 7.05 - 4.73\times10^{-2}[\%\mathrm{Ti}] - (1.05+0.66[\%\mathrm{Ti}])\times10^{-3}(T-1530)$$

(cf. *ISIJ Int.*, **45** (2005), 312)

Ironmaking

Improvement in blast furnace reaction efficiency through the use of highly reactive calcium rich coke

S.NOMURA et al.

A method to produce coke in 'lump' form with high strength and reactivity through the addition of a catalyst was investigated in order to improve blast furnace reaction efficiency. The addition of Ca compounds to coal before carbonization was found to considerably increase the reactivity of the coke at a low temperature range in the thermal reserve zone of a blast furnace. Furthermore it was proved that strong, highly reactive 'lump' form coke could be produced by adding a Ca-rich non-caking coal and adjusting the coal blend composition. Based on this fundamental study, the Ca-rich coke was successfully produced in coke ovens on a commercial scale, both at Kimitsu and Muroran works. The use of the Ca-rich coke in the Muroran No. 2 blast furnace was found to cause a decrease in the reducing agent rate by 10 kg/t-p. This technology, producing coke of high reactivity and strength through catalyst addition, is promising as a means of improving the reaction efficiency of a blast furnace.

(cf. *ISIJ Int.*, **45** (2005), 316)

Steelmaking

Comparison between standard and renormalization group k–ε models in numerical simulation of swirling flow tundish

Q.HOU et al.

Because of the introduction of a cylindrical swirling chamber into a neotype tundish, the Swirling Flow Tundish (SFT), the numerical simulation becomes difficult for this kind of tundish by the standard two-equation k–ε turbulence model. So another kind of k–ε turbulence model, the Renormalization Group (RNG) k–ε turbulence model derived from the theory of renormalization group, was adopted and compared with the standard one. Both of these two kinds of turbulence models were used to simulate the flow patterns in SFT on staggered grid systems based on Finite Volume Method (FVM) with SIMPLER algorithm for steady 3D and incompressible Newtonian turbulent flows. The comparison of simulation results from these two models shows that the RNG k–ε turbulence model for SFT leads quicker convergence than the standard one. Unsymmetrical flow patterns were obtained and the grid independence of this mathematical model for SFT was also discussed. The theoretical analyses of forces on particle, turbulent kinetic energy distribution and lower flow velocity behind dam and weir show that there will be a good effect for non-metal inclusion aggregation and separation with the swirling chamber.

(cf. *ISIJ Int.*, **45** (2005), 325)

Mathematical model for growth and removal of inclusion in a multi-tuyere ladle during gas-stirring

L.T.WANG et al.

A three-dimensional mathematical model has been developed to predict the growth and removal of inclusions during gas stirring in a multi-tuyere ladle. In the model, the efficiency of inclusions removal have been investigated under three different collision mechanisms of Brownian collision, turbulent collision and Stokes collision. Importance of the three approaches of wall adhesion, Stokes flotation and bubbles adhesion to remove inclusions has been analyzed. The results indicated that inclusions growth resulting from turbulent collision is most important and that effect of Stokes collision is remarkable as size of inclusions and difference in size of two particles increase, while inclusion growth resulting from Brown collision is negligible. Removal by Stokes flotation is main manner for large inclusions, while inclusion removal by wall adhesion is negligible. The smaller bubbles contribute the higher efficiency of inclusion removal.

(cf. *ISIJ Int.*, **45** (2005), 331)

Casting and Solidification

Effects of dynamic recrystallization on γ grain refinement and improvement of micro segregation of as cast austenite in 9% Ni steel

S.HOTTA et al.

Effects of dynamic recrystallization on γ grain refinement and improvement in micro segregation of elements such as Ni and Mn of as cast austenite in 9% Ni steel were investigated by two kinds of experimental methods. The first one was a hot compression test using the specimens prepared from the strand cast slab and the hot rolled plate of 9% Ni steel, and the other was a hot tensile straining test in the austenitic region after levitation melting and solidification. In the hot compression test, variations in onset strain and flow stress of steady state flow of dynamic recrystallization with hot deformation conditions were investigated. The onset strain was found to decrease below 0.25 at the temperatures above 1523K and the strain rate below $1\times10^{-2}\,s^{-1}$. The activation energy value obtained from steady state flow stress was 421 kJ/mol. Dynamically recrystallized γ grain size in as cast austenite of this steel was controlled simply by Z value with no dependence on the initial γ grain size. This beneficial feature of dynamic recrystallization was confirmed by the experiment of tensile straining in austenite formed after levitation melting and solidification, where extremely coarse initial γ grain size of around 1.9 mm was markedly refined down to 140 μm by straining such a small strain as 0.40. Micro segregation ratio of Ni and Mn in the strand cast 9% Ni steel examined by EPMA analysis was 1.20 and 1.36, respectively. These values were found to decrease continuously with reduction in strain rate in hot deformation of austenite. That is, dynamic recrystallization in austenite taken place at lower strain rate deformation is much more effective for homogenization of segregated elements compared with high strain rate deformation.

(cf. *ISIJ Int.*, **45** (2005), 338)

Instrumentation, Control and System Engineering

Application of sequential quadratic programming method to temperature distribution control in reactor furnace

K.ISHIMARU et al.

Recently, various studies have been undertaken to examine the inner furnace phenomena of a blast furnace. These studies are limited, however, to the evaluation of furnace performance while a designed method of furnace control remains unfulfilled. This paper proposes a method of estimating temperature distribution in a reactor furnace using boundary data in order to control inner target furnace temperature distribution. Initially, a simplified furnace simulation program for the calculation of inner furnace gas flow, pressure and temperature distribution is developed. Following that, the simulator is used to estimate and control inner furnace temperature distribution. In the estimation, boundary data such as temperature and pressure, measured near a furnace wall, are used in the furnace simulation. Then, for the control of inner furnace temperature distribution, necessary values for gas blowing at the bottom of the furnace and the burden supply at the top of the furnace are used. Both for the estimation and the control of the inner furnace temperature distribution, a sequential quadratic programming method, a method of the iterative optimization, is applied. In our method, an estimation of inner furnace temperature distribution is done as preparation for the determination of furnace control variables. Through numerical experiments, the validity of our method is demonstrated, showing that the temperature distribution in a furnace can be regulated to the desired one after iterative control operations.

(cf. *ISIJ Int.*, **45** (2005), 347)

Forming Processing and Thermomechanical Treatment

Analysis of water cooling mechanism by impinging jet for hot rolled wire rod

S.-K.SEE et al.

The pre-cooling system used in the cooling process of the hot rolled wire rod is a system that sprays cooling water at high pressure to cool the fast-moving wire rod to a required temperature when the rod passes through the cooling nozzle of the cooling box. The influence of the flow phenomenon of this cooling nozzle affecting the rod temperature and the factors affecting the cooling efficiency were examined through experiments and numerical analysis. The confined-type cooling nozzle showed a phenomenon where secondary flow or vortex was produced on the flow depending on the existence of chambers and variations in the Reynolds number, and the production of such vortex affected the rod cooling efficiency phenomenon. The wire rod cooling efficiency can be said to be most effective at a point where the wire rod and water jet impinge due to flow increase, *viz*, the Reynolds number increase. It is believed that the optimal conditions featuring excellent cooling efficiency can be deduced in the future by analyzing the flow conditions and design conditions.

(cf. *ISIJ Int.*, **45** (2005), 356)

Surface Treatment and Corrosion

Improvement in surface brightness and prediction of spangle formation time in a continuous galvanising line through heat balance

M.DUTTA et al.

Galvanised spangle products from the continuous galvanising line-2 (CGL-2) at Tata Steel used to exhibit significantly lower ratio of bright to dull spangles, compared to CGL-1 products. The solute enriched surfaces of dull areas are more susceptible to premature darkening on external exposure. An effort was made here to understand this problem and improve the surface quality of spangle products from CGL-2, as well as to predict the end of zinc solidification *i.e.* the spangle formation time on steel sheets through heat balance study.

Attention was paid on a few parameters such as strip temperature before entry to zinc bath, bath temperature and line speed. A comparative heat balance calculation for zinc solidification revealed that the total heat required to be removed was more in case of CGL-2, whereas the amount of cooling after galvanising was less as compared to CGL-1. This results in extended solidification in CGL-2 during which more solute rejection may occur producing more dull areas. Based on these observations plant trials were carried out at lower temperature of zinc bath, and the bright areas from coil samples were measured. An improvement in bright areas from 25–30% to 35–40% was observed. The surface brightness improved up to 56% at lower line speed. The heat balance calculation also predicted the approximate positions of the formation of spangles at the end of zinc solidification, which were close with actual observations in the plant.

(cf. *ISIJ Int.*, **45** (2005), 366)

Accelerated corrosion behavior due to alternating dry–wet conditions for LP steam turbine materials of fossil power plants

M.HIRANO et al.

The materials of the attachment near the last stage of low-pressure steam turbines in power plants will be exposed to a severe corrosion condition due to the concentration of corrosive chemicals produced by the alternating dry and wet environment, a phenomenon caused by the frequent shutdown and the load change of power plants. The corrosion behavior of typical low-pressure steam turbine materials is evaluated mainly by tests under dry–wet conditions. An increase in the concentration of sulfate ion and chloride ion in waters enhanced the general corrosion particularly for the 3.5NiCrMoV rotor steel. As for 12Cr blade steel, the coexistence of sulfate ion and chloride ion accelerated the general corrosion. An alternating dry–wet condition increased the maximum corrosion pit depth of 3.5NiCrMoV steel remarkably with the application of stress. The pitting corrosion potential of 3.5NiCrMoV steel showed almost the same values in all water qualities tested. However, the coexistence of Cl^- and DO (dissolved oxygen) lowered the pitting corrosion potentials of 12Cr steel. From the consideration between the corrosion and the Cr content in corrosion films, it is clearly evident that the Cr content in the films controls the corrosion resistance.

(cf. *ISIJ Int.*, **45** (2005), 373)

Transformations and Microstyructures

Ferrite/pearlite band prevention in dual phase and trip steels: model development

W.XU et al.

A model for predicting the conditions for ferrite/pearlite band prevention in dual phase and TRIP steels has been developed. The competition between processing parameters such as the austenitisation time and temperature, the transformation temperature and microchemical segregation wavelength is explored. The effects of alloy composition in the tendency to form ferrite/pearlite bands are quantified. A simple formula combining processing parameters and compositions for describing band formation is presented. The calculations show that the most prominent factor for preventing banding is the control of the microchemical wavelength. In addition to C and Mn, Al and Si concentrations have shown to play a smaller but significant role in band formation behaviour.

(cf. *ISIJ Int.*, **45** (2005), 380)

Role of pre-deformation in age hardening of a niobium-microalloyed steel

Z.-X.YUAN et al.

The effect of pre-deformation on the age hardening of a niobium-microalloyed steel is investigated by virtue of mechanical testing in conjunction with microstructural observations. The steel is aged at three temperatures 600°C, 640°C and 680°C, respectively, after solution-treated at 1200°C. The precipitation of Nb(C, N) is markedly accelerated by a pre-deformation of 15% prior to ageing, resulting in very fine particles being formed and a considerable increase in the strength of the steel with no large decrease in the ductility. Compared with the hot-rolled state, the yield strength of the deformed steel increases by about 280 MPa while that of the undeformed steel only by about 60 MPa after peak-aged at 640°C. Overall, the yield strength of the deformed steel may reach about 710 MPa with an elongation of about 19%.

(cf. *ISIJ Int.*, **45** (2005), 388)

Ultra-fine ($\alpha+\theta$) duplex structure formed by cold rolling and annealing of pearlite

T.FURUHARA et al.

The ferrite (α)+cementite (θ) duplex structure formed by heavy cold rolling and annealing of pearlite was studied in an Fe–1.4Cr–1.0C (mass%) alloy. Cold-rolled pearlite structure is inhomogeneous consisting of three components; (1) irregularly bent lamellae (IBL), (2) coarse lamellae with shear band (CLS) and (3) fine lamellae (FL) as was previously reported by the present authors. Misori-