（＊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

Progress of chinese steel industry and technology (Review)

K.XU

The rapid development of Chinese steel industry meets the challenges encountered in the process of the Chinese industrialization. When the continuous and rapid development is in progress in the every aspects of the domestic economy, there are higher demands on the variety and quality of the steel materials during the industry's upgrade and the challenge from environment. Chinese steel industry must satisfy the market by increasing its competitiveness, developing and applying new technologies to steel production processes. This phenomenon is also in agreement with the current trend of development in the world steel industry. This paper will summarize the features and structure changes of Chinese steel industry and discuss its direction of the technology development.

(cf. *ISIJ Int.*, **48** (2008), 557)

Mgo effect on the hydrothermal solidification of blast furnace slag

T.YOSHIKAWA et al.

Due to the large generation of blast furnace (BF) slag, new recycling processes that produce valuable materials are required. The authors have focused on a hydrothermal treatment of BF slag using waste heat exhausted from iron- and steelmaking processes. Although BF slag contains Al_2O_3, which is well known to have a deteriorating effect on hydrothermal reactions, especially CaO–SiO_2 hydration, it can be successfully solidified by hydrothermal treatment above 523 K. We focused on the contribution of MgO in BF slag to the hydrothermal reactivity in the slag system. The hydrothermal solidification of synthesized CaO–SiO_2–Al_2O_3 and CaO–SiO_2–Al_2O_3–MgO slags were investigated in the present work. The hydrothermal solidification behaviors of slags are discussed based on the degree and type of crystal formation during the hydrothermal process.

(cf. *ISIJ Int.*, **48** (2008), 564)

Ironmaking

Effects of coal inertinite size on coke strength

Y.KUBOTA et al.

In order to improve coke strength by the technique of coal size control, it is essential to understand the relationship between inertinite size and coke strength. The size and area of the inertinite in coke was measured with a microscope and an image analysis technique and the effect of the inertinite size on coke strength was investigated. Moreover the reason why DI^{150}_{-6} leveled off at an inertinite size of 1.5 mm was investigated.

The results are follows.

(1) When the inertinite size is between about 1.5 mm and 5 mm, the surface breakage product (DI^{150}_{-6}) decreases as the size of inertinite in coke diminishes. When the inertinite size is over about 5.0 mm, volume breakage product (DI^{150}_{6-15}) decreases as the inertinite size diminishes.

(2) Effects of 1% increase/decrease of different size groups of inertinite on DI^{150}_{-6} and DI^{150}_{6-15} were clarified.

(3) According to Hertzian contact theory and Griffith equation, it is estimated that cracks under 0.5 mm do not grow by fall of coke in the drum tester. The critical inertinite size (1.5 mm) is an appropriate value for this critical crack size (0.5 mm), because the size of the crack around the inertinite grain is equal to or smaller than the size of the inertinite grain.

(cf. *ISIJ Int.*, **48** (2008), 570)

Carbonization behaviour of woody biomass and resulting metallurgical coke properties

T.MATSUMURA et al.

The technology using waste wood from construction and thinned wood that are not recycled in the woody biomass as one of raw materials for producing metallurgical coke was examined in detail by adding them to coal and carbonizing them. In the carbonization tests, four types of woody biomasses showed substantially almost the same results in respect to material balance and composition of carbonized products. Compared with raw woods, woody biomasses compressively formed to not smaller than 10 mm permit an increase in the addition rate to 1.5% while inhibiting the lowering of coke strength. Hot compressive forming at 200–350°C where pyrolysis of woody biomass occurs inhibits the lowering of coke strength and will therefore permit an increase in the use of woody biomasses. As a result, the possibility to use as a raw material for the coke manufacturing by adding the compressively formed woody biomass was found.

(cf. *ISIJ Int.*, **48** (2008), 579)

Steelmaking

Approaches for conversion of high phosphorus hot metal to steel for flat products

P.K.TRIPATHY et al.

Consistent production of low phosphorus steel (≤0.015%) from high hot metal phosphorus (~0.230%) in BOF steelmaking is a technologically challenging task. The problem gets compounded if steel is to be tapped at high temperature (≥ 1 700°C).

This paper deals with the continuing efforts and experiences of producing low phosphorus steel at steel melting shop no. 2. Two approaches are mentioned. First approach being optimization of slag chilling process near the blow end which has enabled better control of steel phosphorus in high temperature heats. Other approach delves into an extensive data mining study to understand dephosphorization behaviour in BOF. Data mining throws few interesting findings based on which underlying mechanism of BOF dephosphorization has been proposed.

(cf. *ISIJ Int.*, **48** (2008), 585)

Casting and Solidification

Numerical simulation of the effects of electromagnetic brake and argon gas injection on the three-dimensional multiphase flow and heat transfer in slab continuous casting mold

H.YU et al.

A 3-D mathematical model has been developed to study the multiphase phenomena of magnetic field, flow field and temperature distribution of molten steel and inclusion behaviour, considering the coupled effects of electromagnetic brake (EMBR) and argon gas injection in the slab continuous casting mold with high casting speed. The effects of EMBR and argon gas injection on the flow and temperature of molten steel and inclusion removal rate have been investigated. Simulation results indicate that EMBR can slow down the flow velocity of molten steel effectively, especially near the meniscus; the areas of upper and lower re-circulation zones are reduced and temperature distribution of molten steel is more uniform and the temperature gradient is reduced; but it has no helpful for the removal of small inclusions. The argon gas injection can increase the molten steel flow up tendency in the upper re-circulation area duo to the buoyancy effect of ascending argon gas bubbles near the submerged entry nozzle (SEN) and be in favour of the floating up of inclusion particles, and temperature in the upper re-circulation zone increases. The increasing of argon gas flow rate results in a stronger vortex flow zone near the free surface, especially near the SEN and easily forms a secondary eddy flow with EMBR, which impacts the fluctuation of free surface and the slag entrapment. The double action of EMBR and argon gas injection can further increase the temperature in the upper re-circulation zone, especially near the meniscus, and the floating up rate of inclusions are also improved and the inclusions to be trapped into solidified shell is reduced.

(cf. *ISIJ Int.*, **48** (2008), 591)

Chemical and Physical Analysis

The application of infrared spectrophotometry to analysis of dehydration process of inorganic hydroxides and evaluation of monolithic refractories

Y.SAITO et al.

Inorganic oxides are widely used as raw materials and formed as byproducts in iron and steelmaking processes. Some inorganic oxides such as CaO and MgO absorb water to form inorganic hydrates. When hydrates form, they expand. On the other hand, hydrates often dehydrate on heating to form oxides. To analyze hydrates in oxides is therefore important in order to examine hydration and dehydration processes.

This paper concerns with the analysis of dehydration processes of $Mg(OH)_2$, $Ca(OH)_2$ and $Al(OH)_3$ in which high temperature infrared spectrophotometry and thermogravimetry (TG) were used to elucidate the expansion behavior of monolithic refractories. Two monolithic refractories, which contained the same amount of MgO, were investigated with hydration. $Mg(OH)_2$ was observed in the samples

that expanded after pressed. No $Mg(OH)_2$ was observed in the sample that did not expand after pressed. In addition, infrared spectrums give the amount of $Mg(OH)_2$. Infrared spectrophotometry can be used for the quantitative analysis of the small amount of inorganic hydrates in oxides.

(cf. *ISIJ Int.*, **48** (2008), 599)

Forming Processing and Thermomechanical Treatment

Scale accretion on homogenization furnace rollers in compact strip production mills and its densification mechanism

Y.-Z.ZHU et al.

SEM, EDS, XRD, ICP-AES and DTA were used to analyze the densification mechanism of the scale accretion on homogenization furnace rollers in compact strip production line. It was discovered that the accumulated scale was composed of many layers. A thin outer layer wa relatively loose and thick inner layers were hard and densified. There were great differences in phase types between the loose and the densified layers. The loose layer was composed of mainly Fe_2O_3 with minor Fe_3O_4. However, the densified layers consisted of FeO and Fe_3O_4; FeO was formed on billets at high temperatures, which was transformed to Fe_3O_4 at low oxygen partial pressure. Owing to the weight of the billet, the picked-up scale became densified. A great amount of wustite $Fe_{(1-x)}O$ in a shape of star was discovered distributing dispersedly in the scale accretion, resulting in a higher strength of it. Additionally, the minor residual elements of low melting point, such as Mg, As, Cu from billet and sulfur from burning gas were melted, resulting in an acceleration of the densification process. On the contrary, the outer surface layer of the scale accretion was partly changed to Fe_2O_3 by the oxygen in the furnace in blow-off process, leading to a looselayer.

(cf. *ISIJ Int.*, **48** (2008), 605)

Numerical study of a planar liquid jet impinging on a solid substrate

H.FUJIMOTO et al.

The flow structure of a planar water jet impinging on a solid substrate was studied by means of three-dimensional numerical simulations. In the system studied, the planar water jet issues from a slot nozzle into quiescent air, falls vertically, impinges on a horizontal smooth surface, and then a thin film forms on the solid surface. The liquid flow was assumed to obey the Navier-Stokes equations in three-dimensional Cartesian coordinates. The simulations took into account the effects of gravity, viscosity, and surface tension at the free surface. Experiments were also conducted for model validation. The predictions of the model were in reasonable agreement with the experimental results. The effects of the velocity profile at the nozzle exit, the liquid flow rate, and the nozzle-plate distance on the flow structures were investigated. The physics of these phenomena are discussed in detail from the viewpoint of fluid mechanics.

(cf. *ISIJ Int.*, **48** (2008), 610)

Numehrical simulation of two droplets impinging successively on a hot solid in the film boiling regime

T.MINAMIKAWA et al.

The deformation mechanics of two droplets impinging successively on a hot solid at small impact velocities was investigated by carrying out computer simulations. The conservation equations for mass, momentum, and energy for unsteady incompressible viscous fluids in an axisymmetric coordinate system were approximated and solved with a finite difference method, taking account of gravity, viscosity, and surface tension. It was assumed that a thin vapor layer forms between the water droplet and the solid surface immediately after impact. The numerical results were compared with those of experiments. It was found that the liquid deforms into a crown shape during the successive impacts. The fluid mechanics of the interactions of the droplets is discussed in detail.

(cf. *ISIJ Int.*, **48** (2008), 618)

Welding and Joining

Microstructural evaluation and ultrasonic characterization of TLPD bonded 6061-SiCp composite

J.MAITY et al.

Microstructural evaluation during transient liquid phase diffusion (TLPD) bonding of extruded aluminium based metal matrix composite (6061-15 wt% SiC_P) using 50 μm thick copper interlayer was investigated by optical microscopy, scanning electron microscopy (SEM) together with SEM-based energy dispersive X-ray spectroscopy (EDS) and pulse echo ultrasonic test. Microstructural changes in the joint region were examined at five different holding time (20 min, 1 h, 2 h, 3 h and 6 h) for a bonding temperature of 560°C under two different applied pressures (0.1 MPa and 0.2 MPa). Kinetics of the bonding process was significantly accelerated in presence of reinforcement (SiC). This acceleration is attributed to the increased solute diffusivity through defect-rich SiC particle/matrix interface and porosity. The segregated particle at bond interface caused significant attenuation of ultrasonic wave, especially at lower bonding time. The attenuation effect decreased with increasing bonding time as width of particle segregation decreased.

(cf. *ISIJ Int.*, **48** (2008), 623)

Development of titanium weld metal reinforced by titanium mono-boride

H.TERASAKI et al.

In order to reinforce the mechanical properties of titanium weld, titanium mono-boride (TiB) was dispersed in the weld metal with gas tungsten arc welding process. The microstructure difference of weld metal between the TiB-reinforced titanium and pure-titanium were made clear by the observation in the surface and cross section of weld metal. The distributions of TiB were particular in welding and the crystal orientation analysis showed the TiB was distributed between cell microstructures. It was found that the hardness increased in TiB-reinforced weld metal suggesting increasing of tensile strength. Furthermore, the effect of boron addition on the weld pool convection was found and the mechanism was discussed.

(cf. *ISIJ Int.*, **48** (2008), 631)

Surface Treatment and Corrosion

The role of texture and microstructure in optimizing the corrosion behaviour of zinc hot-dip coated steel sheets

H.ASGARI et al.

Protective metallic coatings based on Zn are usually used to protect steel against corrosion. When coated steel sheets are subjected to corrosive environments, its corrosion behaviour is affected due not only to changes of the coating texture, but also of the microstructure. The aim of this work was to study the effects of texture components and microstructure on the corrosion behaviour of hot-dip galvanized coatings. Texture components of the coatings were evaluated employing X-ray diffraction whilst its corrosion resistance was analyzed by means of Tafel polarization and salt spray tests. Microstructure of the coatings was studied using SEM and EDS analysis. From the experimental results, it was concluded that increasing the lead content of the zinc bath would decrease the texture coefficient of basal plane component and conversely, the texture coefficient of other components such as high angle pyramids, low angle pyramids and prism planes would be increased. Besides, gamma layer thickness increases as the lead content of the zinc bath increases. In addition, it was observed that greater basal texture coefficient and smaller gamma layer thickness would result in better corrosion resistance of hot-dip galvanized coatings.

(cf. *ISIJ Int.*, **48** (2008), 635)

Effects of small amounts of molybdenum, tungsten, or tin additives on the morphology and orientation of electrodeposited zinc

H.NAKANO et al.

Zn was electrodeposited galvanostatically on a steel sheet at 1 500 A/m^2 in an agitated sulfate solution of pH 2 at 40°C to investigate the effects of small amounts of Mo, W, or Sn additives on the morphology, crystal orientation and lightness of the deposited Zn. Neither Mo nor W codeposited with Zn, and both showed hardly any effect on the morphology of the deposited Zn. Mo and W increased the orientation of the (0001) plane of Zn, but did not change the overpotential for Zn deposition. Sn codeposited with Zn and, as a result, platelet crystals of Zn did not form. Sn increased the crystal orientation of the (0001) and $(10\bar{1}3)$ planes of Zn as a result of a decrease in the overpotential for Zn deposition. The lightness of the deposited Zn depended on its crystal orientation and surface roughness. At a coating mass of 20 g/m^2, Sn, Mo and W enhanced the lightness of Zn by increasing the orientation of its (0001) and $(10\bar{1}3)$ planes. At higher coating masses, however, this enhancement in lightness disappeared as a result of the increase in surface roughness induced by the presence of the inor-

ganic additives.

(cf. *ISIJ Int.*, **48** (2008), 641)

Effect of Cu addition on delayed fracture resistance of low carbon steel for 1 470 MPa grade electric resistance welded tube

S.TOYODA et al.

The effect of chemical composition on delayed fracture resistance, taking into consideration the application of a 1 470 MPa grade thin-wall as-rolled electric resistance welded (ERW) tube to automotive structural parts, was investigated. Chemical composition of the base steel alloy was 0.18%C–0.4%Si–1.8%Mn–0.015%Nb–0.01%P–0.001%S. Cu, Ni, Cr, B and Mo were individually added to the base steel. A 4-point bending test in 1 N-hydrocrolic acid was conducted for quench and tempered specimens. Cu added steel showed the best delayed fracture resistance. After the immersion, a metallic Cu layer was formed on the steel surface. Based on the results of the 4-point bending test, several kinds of 1 470 MPa grade ERW steel tubes were prepared and evaluated for their delayed fracture resistance. Cu added steel tubes showed excellent delayed fracture resistance in a cyclic corrosion condition with salt water spray, as well as in hydrocrolic acid. Cu accumulation on the rust-steel interface was observed by electron probe microanalysis (EPMA). An atmospheric corrosion test lasting 12 years was also conducted. Delayed fracture resistance as evaluated by (a) an immersion test in hydrochloric acid, (b) a cyclic corrosion test with salt water spray, and (c) an atmospheric corrosion test, showed good correlation with each other. Based on the results above, two models are proposed for the mechanism of delayed fracture suppression by Cu addition: (1) Cu suppressed cathodic reaction and hydrogen entry at sulfide inclusion, and (2) Cu suppressed hydrogen entry by stabilization of sulfuric-ions as an insoluble compound.

(cf. *ISIJ Int.*, **48** (2008), 647)

Transformations and Microstructures

Design of the directly air-cooled pearlite-free multiphase steel from CCT diagrams developed using ANN and dilatometric methods

S.K.GHOSH et al.

Present study aims to predict the effect of Ti, B, Cu and Ni on continuous cooling transformation diagrams of low carbon (0.04–0.05 wt%) steels by artificial neural network model. The predicted results are validated with dilatometric studies. Comparison of the phase fields in different continuous cooling transformation diagrams demonstrated that in Ni containing 1.5 wt% Cu-added Ti–B microalloyed steel it is possible to achieve dual phase (ferrite–martensite) microstructure in directly air-cooled condition (*i.e.*, at cooling rate close to 1°C/s) by suppressing pearlite formation. Addition of Cu has remarkably improved the hardness of the dilatometric samples.

(cf. *ISIJ Int.*, **48** (2008), 656)

Effects of oxide particles and solute elements on austenite grain growth in Fe–0.05mass%C and Fe–10mass%Ni alloys

A.V.KARASEV et al.

The inhibition effects of oxide particles and solute elements on austenite grain growth have been studied in an Fe–0.05mass%C and Fe–10mass%Ni alloys deoxidized with Mn–Si, Ti, Mg, Zr and Ce as a function of content of soluble deoxidant elements and holding time at 1 200°C. Total surface area of austenite grains per unit volume which is inversely proportional to austenite grain size is analyzed as a function of total surface area of particles per unit volume and content of soluble deoxidant elements. It is found that in Mn–Si, Ti and Mg deoxidations, the austenite grain size is controlled only by the effect of particle pinning, while in Zr and Ce deoxidations the austenite grain size is controlled by both particle pinning and solute drag. The inhibition effect of soluble Zr and Ce increases significantly with increasing their contents. The effect of particle dragging in Ce deoxidation increases with increasing the holding time at 1 200°C. The contribution of particle pinning, particle dragging and solute drag to austenite grain growth is estimated as a function of deoxidant elements and holding time at 1 200°C.

(cf. *ISIJ Int.*, **48** (2008), 665)

Mechanical Properties

Deep drawabilty of electro-deposited pure iron having an extremely sharp ⟨111⟩//ND texture

N.YOSHINAGA et al.

Electro-deposited pure iron having an extremely sharp ⟨111⟩//ND fiber texture has extraordinarily excellent deep drawability. The relaxed constraints models based on Taylor theory cannot predict such high *r*-values. This excellent deep drawability seems to arise not only from the sharp ⟨111⟩//ND texture but also significantly from the specific morphology of the microstructure, *i.e.* needle-shaped fine grains elongated in the normal direction.

(cf. *ISIJ Int.*, **48** (2008), 674)

Prediction of ultimate behaviors in cold-formed steel bolted connection by the introduction of initial geometric imperfection in FE modeling

T.S.KIM et al.

Experimental research and nonlinear finite element analysis for the structural behaviors of single shear test on bolted connections fabricated with cold-formed stainless steel have been conducted. Failure criteria for prediction of failure mode of bolted connections under static shear and out-of-plane deformation, *i.e.*, curling criteria were proposed based on experimental data for calibration of FE modeling. Failure mode and ultimate strength predicted by recommended FEA procedures with solid element showed a good correspondence with those of previous test results and the validation of FEA method was verified. The previous numerical analyses of bolted connection were carried out on geometrically perfect specimens. However, it has been known that geometric imperfection of thin-walled members must be considered in a FE model to simulate the actual shape of specimen. Therefore, in this paper, parametric studies were carried out based on the validity of numerical modeling of bolted connections in cold-formed stainless steel so that authors investigated the influence of initial geometric imperfection of connected plate on its structural behavior. Solid element and shell element with reduced integration were introduced as an element type and included two types of geometric imperfection. Consequently, FE modeling technique of cold-formed stainless steel bolted connection introducing initial imperfection to compensate the function of shell element and to induce the curling was proposed.

(cf. *ISIJ Int.*, **48** (2008), 678)

New Materials and Processes

Numerical study of microwave heating of micrometer size metal particles

M.SUZUKI et al.

Absorption of microwave energy in conductive nonmagnetic spherical particles is analyzed by means of finite element method. The frequency of the microwave is 2.45 GHz. To find out roles of the electric and magnetic fields in the heating process, conditions of the electric and magnetic anti-nodes in a standing wave are simulated. Results clearly show that single metallic particles are mostly heated by the magnetic component of the electromagnetic field. Density of the absorbed energy has maximum at some fixed particle radius, which equals to 3.3 μm for the case of copper particles. Penetration length into multi particle system is estimated.

(cf. *ISIJ Int.*, **48** (2008), 688)

Social and Environmental Engineering

Evaluation of selective separation of phosphorous components from plating baths using schwertmannite

M.OKIDO et al.

Selective separation of phosphorous ion compounds in plating baths is of great interest. Schwertmannite, found as a strong P-sorbent in our pervious works, was used for this purpose as an inorganic chemical adsorbent. The effect of pH as a significant operating parameter on P-adsorption on schwertmannite in this process as well as on the stability of schwertmannite was thoroughly investigated. The experimental results showed that the hypophosphite $H_2PO_2^-$ was relatively difficult to exchange with sulfate units in schwertmannite in comparison with monoorthophpsphite $H_2PO_3^-$ and monoorthophosphate $H_2PO_4^-$. Moreover, batch kinetic trials revealed that the obtained data was fairly fitted to pseudo-second-order models.

(cf. *ISIJ Int.*, **48** (2008), 692)

Microwave carbo-thermal reduction for recycling of Cr from Cr-containing steel making wastes

N.YOSHIKAWA et al.

In this study, Cr-containing steel making slag and pickling sludge were reduced with graphite by mi-

crowave (MW) heating. The reduced metal (alloy) particles were obtained and their compositions were determined. Pure Cr_2O_3 was reduced at lower temperature than expected from thermodynamics.

Fundamental studies on MW heating of Cr_2O_3 were performed using a multi-mode and a single mode MW applicators in order to investigate the enhanced reaction kinetics. It was demonstrated that heating of Cr_2O_3 requires incubation period before onset of the sudden temperature rise. Cr_2O_3 was preferentially heated in the electric (*E*-) field of MW and metal pieces were formed.

It was pointed out that the MW heated specimen had inhomogeneous temperature distribution, the temperature could be measured at the localized region and/or it is an average of the temperature distribution in a miro-scale. The reduction might have occurred in the high temperature region, preferentially. In order to account for generation of the inhomogeneous distributions, two possibilities are considered. First, as the enhanced heating behavior in *E*-field, dielectric heating mechanism of Cr_2O_3 is likely, and its permittivity (loss factor) has large temperature dependence. Therefore, small initial temperature fluctuation was amplified to become the local temperature difference (hot spot). Second, occurrence of local arcing enhanced the kinetics and formation of metal pieces.

(cf. *ISIJ Int.*, **48** (2008), 697)

Estimation of steel consumption and obsolete scrap generation in Japan and Asian countries in the future

Y.IGARASHI et al.

The present flows of steel scraps in Japan, China, South Korea and Taiwan are described, and a dynamic model that analyzes future scrap flows was developed. To estimate obsolete scrap recovery, a population balance model (PBM) was used for Japan, South Korea and Taiwan. The PBM dynamically estimated the amount of discarded steel by taking into account steel input into a society by end use and the lifetime distributions of each end use. For China, obsolete scrap recovery was estimated using a leaching model, which used the steel stock and the recovery ratio of obsolete scraps. Three different methods were applied to forecast future steel input for each country. The first method applied the assumption that steel demand in the future remains at the present level. The second method applied a logistic curve to estimate future steel stock. The third method applied regression equations to future steel input by end use. GDP and population were used as variables. Finally, the steel input forecasts produced by each method were substituted into the obsolete scrap recovery estimation model. The logistic curve method estimated that in 2030 obsolete scrap recovery would be 29 million tons in Japan, 83 million tons in China, 20 million tons in South Korea, and 3.7 million tons in Taiwan.

(cf. *ISIJ Int.*, **48** (2008), 703)