（＊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

Manganese Distribution Equilibrium between CaO–Fe_tO–SiO_2–MnO–P_2O_5–(Al_2O_3) Slags and Carbon Saturated Iron

C.-y.ZHU et al.

In order to find out the optimum thermodynamic conditions for hot metal demanganization and predict the manganese content after demanganization pretreatment, the equilibrium experiments for the measurement of manganese distribution between CaO–Fe_tO–SiO_2–MnO–P_2O_5–(Al_2O_3) slags with silver were carried out in an iron crucible at 1 573–1 673 K under pure argon atmosphere. The manganese contents in silver were converted to that in the carbon-saturated iron using the known thermodynamic data. The distribution ratios between slags and carbon-saturated iron were calculated. The results indicate that manganese distribution ratios increase with a decrease in slag basicity, and they increase with an increase in Fe_tO content in the slags at first, then they decrease with an increase in content of Fe_tO. The maximum manganese distribution ratio is 576.6 with the Fe_tO content of 50.30 mass% and the slag basicity of 0.27 at 1 623 K, and the correspondent manganese content in the carbon saturated iron is 0.015 mass%. The manganese distribution ratios decrease with an increase in MnO content in the slags. On the other hand, Al_2O_3 content in the slag has little influence on the manganese distribution ratios. The equilibrium manganese distribution ratios obtained in the present work were summarized as a function of slag compositions and temperature by the multiple regression method.

(cf. *ISIJ Int.*, **48** (2008), 123)

Fabrication of Low Temperature Foaming Glass Materials Using Hydrothermal Treatment

T.YOSHIKAWA et al.

In order to prepare functional porous glasses, the fabrication of low temperature foaming glass materials was achieved using a hydrothermal treatment. The hydrothermal hot pressing technique was applied to 63mass%SiO_2–27mass%Na_2O–10mass%B_2O_3 glass at 523 K. The water releasing behavior of the glass was analyzed by TG-DTA. A macroscopic change was observed after the heat treatment at 423–673 K and foaming was exhibited at temperatures as low as 473 K. The mechanism for foaming of the hydrothermally treated glass is discussed from the microstructure change observed with laser microscopy. Furthermore, the application of hydrothermally treated glass is proposed and demonstrated.

(cf. *ISIJ Int.*, **48** (2008), 130)

Ironmaking

Design of Blast Furnace Crucibles by Means of the Nodal Wear Model

M.F.BARBÉS-FERNÁNDEZ et al.

The Nodal Wear Model (NWM) is used to explain and quantify the causes for the occurrence of different corrosion profiles observed in the hearth of blast furnaces during their campaign, and, as a consequence it is possible to use the NWM to define the most appropriate refractory materials for designing and constructing blast furnace crucibles. The NMW is based in three critical parameters which are the temperature at the interface between pig iron and the refractory lining (T_i), the temperature difference between such a point and at an adjacent node (ΔT_i), and the difference in temperature between the bulk liquid and that at the refractory–iron interface ($T^{\infty}-T_i$). If the design and construction criteria rest upon reaching maximum durability of refractory linings, then, according to the NWM, all changes that minimize the values of T_i and ΔT_i, and maximize $T^{\infty}-T_i$ should be attempted.

(cf. *ISIJ Int.*, **48** (2008), 134)

Desulfurization Technology in the Blast Furnace Raceway by MgO–SiO_2 Flux Injection

T.ORIMOTO et al.

This paper presents a study on desulfurization technology in the steel industry, with attention focused on the removal of sulfur that forms acid rain, which has been creating various global problems. The study was confined to the technology that injects a mixture of serpentine and pulverized coals. Thermodynamically, a magnesium gas producing reaction occurs when magnesium oxide is turned into a hot strongly reducing atmosphere and the resulting magnesium gas forms magnesium sulfide by reaction with the sulfur in the molten iron. By dividing this desulfurization process into a magnesium gas producing reaction and a desulfurization reaction by the magnesium gas, the desulfurization effect of the magnesium oxide flux was confirmed through laboratory experiment. A thermodynamic study on the desulfurization reaction in which SiO gas resulting from the reduction of SiO_2 produces a silicon sulfide gas by reaction with the sulfur in the molten iron revealed that the possibility of desulfurization of the molten iron by the silicon sulfide gas is not negligible.

(cf. *ISIJ Int.*, **48** (2008), 141)

Steelmaking

Dynamic Coupling of Computational Fluid Dynamics and Thermodynamics Software: Applied on a Top Blown Converter

M.ERSSON et al.

A novel modeling approach is presented where computational fluid dynamics software is coupled to thermodynamic databases to obtain dynamic simulations of metallurgical process phenomena. The modeling approach has been used on a fundamental model of a top-blown converter. Reactions between gas–steel, gas–slag, steel–slag and gas–steel–slag have been considered. The results show that the mass transport in the surface area is totally controlled by convection. Also, that a large amount of CO produced during the decarburization might slow down the rate of decarburization in droplets ejected from the bath. For the present simulation conditions reflecting laboratory experiments, it was also seen that the amount of slag (FeO and/or SiO_2) created is close to zero, *i.e.* only gas ($CO+CO_2$) is created as the oxygen jet hits the steel bath. It was also illustrated how an extrapolation of the decarburization rate, sampled from a few seconds of simulation, could be done to get a rough estimate of the carbon content at a later stage in the process as long as the carbon content is relatively high. The overall conclusion is that it is possible to make a dynamic coupling of the Thermo-Calc databases and CFD software to make dynamic simulations of metallurgical processes such as a top-blown converter.

(cf. *ISIJ Int.*, **48** (2008), 147)

Casting and Solidification

Effect of Height and Position of Dams on Inclusion Removal in a Six Strand Tundish

P.K.JHA et al.

The Reynolds-averaged Navier–Stokes equations have been numerically solved to obtain a steady, three-dimensional velocity field inside the six-strand billet caster tundish using the standard k–ε model of turbulence. These steady flow fields so obtained are then used to predict the removal of inclusions from molten steel by solving the inclusion transport equation with the help of a commercial CFD software Fluent 6.1.22. The effects of height and position of dams in the tundish and size of the inclusion particles on percentage inclusion removal were studied. To simulate the chaotic effect of the turbulent eddies on the particle paths; a discrete random walk model was applied during inclusion trajectory calculations. The computational model was first validated with the results reported in the literature a good match was found between the two. It was found that with the increase in the height of the dams, the inclusion removal tendency increased whereas the shifting of the dams towards the outlets decreases the inclusion removal. An increase in the inclusion removal was found with an increase in the inclusion particle size.

(cf. *ISIJ Int.*, **48** (2008), 154)

A New Semi-analytical Model for Prediction of the Strand Surface Temperature in the Continuous Casting of Steel in the Mold Region

M.ALIZADEH et al.

In this research, a new semi-analytical model is presented for the strand surface temperature in the continuous casting of steel. Firstly with a dimensional analysis approach a general relation between the strand surface temperature and the other effective variables such as conductivity of the steel, pouring temperature, casting velocity, distance from the meniscus, volume rate of cooling water, solidus temperature and heat flux density at the meniscus is deduced. The constants appeared as coefficients or powers of variables in presented relation were computed by a numerical simulation of continuous casting for a breakout bloom. The resulted semi-analytical model for strand surface temperature was extended to predict the solidified shell thickness. The resulted semi-analytical model was validated with comparison to experimental, analytical and numerical results of slab, billet and bloom and good agree-

ment was seen. The new presented model at this research is in versus of controllable parameters and specifications of the mold and it can be used for design of a process control system for continuous casting of slab, billet and bloom.

(cf. *ISIJ Int.*, **48** (2008), 161)

The Shell Surface Force Caused by Mould Friction during Slab Continuous Casting

Z.XINYANG et al.

In continuous casting, the lubrication and friction between the mould and the initial solidified strand shell play an important role for achieving the high speed casting and producing a good surface quality of the product. Investigation of the frictional behavior is therefore essential for getting a better online control of the mould processes. In the present work, the measurement of shell surface force caused by mould friction was performed during the slab continuous casting. Friction force was calculated to investigate the periodical variations as well as the effect of tensions and pressures on the solidified shell. Also the comparison of the mould friction in sinusoidal and non-sinusoidal mould oscillation was made. This research provided the test foundations and technical supports for studying the mechanical behavior of casting mould and optimizing the casting variables.

(cf. *ISIJ Int.*, **48** (2008), 170)

Mechanism of the Silicon Influence on Absolute Chilling Tendency and Chill of Cast Iron

E.FRAŚ et al.

In this work an analytical solution of general validity is used to explain mechanism of the silicon influence on the absolute chill tendency (CT) and chill (w) of cast iron. It is found that CT can be related to nucleation potential of graphite (N_v), growth parameter (μ) of eutectic cells, temperature range (ΔT_{sc}), where $\Delta T_{sc}=T_s-T_c$ (T_s is graphite eutectic equilibrium temperature and T_c is cementite eutectic formation temperature) and the pre-eutectic austenite volume fraction (f_γ). It has been shown that silicon additions: 1) impede the growth of graphite eutectic cells through decreasing graphite eutectic growth coefficient μ, 2) expands the temperature range ΔT_{sc}, 3) increases the nucleation potential of graphite N_v, 4) lowers the pre-eutectic austenite volume fraction, f_γ and in consequence the absolute chilling tendency CT decreases. The minimum wall thicknesses for chilled castings, or chill widths, w in wedge shaped castings is related to CT and as Si contents increases, the chill widths, w value decreases.

(cf. *ISIJ Int.*, **48** (2008), 175)

Flux Film in the Mold of High Speed Continuous Casting

M.HANAO et al.

The film, which is formed by mold flux in the continuous casting mold, plays very important roles in terms of lubrication or heat transfer. However, the thickness or structure of it has not been adequately clarified.

In this study, the sample of actual flux film was taken from the continuous casting mold just after the cast, keeping its position as it was during the cast. Thanks to this trial, thickness of the flux film at the meniscus in the mold could be clarified. According to the observation on the flux film section by microscope, the structure of the flux film was discussed, in terms of its crystallization.

Furthermore, based on the results of the observation mentioned above, the heat transfer phenomenon through the flux film in the mold was discussed.

As a result of the discussion, the following conclusions were obtained.

1) The mold flux film can be considered to be about 1 mm. Glassy layer, which has been considered to be molten flux on the top of molten steel during the cast and covered the film just after the cast, can be assumed to make up the film during the cast.

2) The liquid layer in the film is as thick as that is estimated on the basis of mold flux consumption during the cast.

3) In the case that the film at the meniscus in the mold is about 1 mm thick, total thermal resistance of radiation and conduction is equivalent to interfacial thermal resistance between the film and the mold.

4) The reported values of interfacial thermal resistance can be considered to be larger than that in the actual mold during the casting. The reason seems to be that they were measured in conditions without any pressure by the molten steel, like that in the mold. In the actual mold, the interfacial thermal resistance seems to be smaller.

(cf. *ISIJ Int.*, **48** (2008), 180)

Chemical and Physical Analysis

Relationship between Mineragraphy Features of Sinter Ore and Its Gray Histogram

X.LV et al.

The intelligent recognizing and processing system make a great convenience for recognition and measurement of sinter ore mineragraphy. Specially, it's crucial for a successful intelligent system to extract the minerals' features accurately and sufficiently. The paper got the relatively position of peak of the gray histogram in theory by using the calculated model of index of reflection and peak-find model of gray histogram; the parameters like μ and θ^2 of familiar minerals were gotten by statistical averaging with Gaussian gray distribution model, the information about the category and content of minerals can also got by fitting the curve of gray histogram with Gaussian gray distribution model; the feature curves of gray histogram of two minerals were gained by synthesizing two density functions; also the feature parameters such as the number and position of peak and valley of two minerals in different ratios were obtained by differentiating to the distribution functions. The feature parameters, feature curves, and other conclusions lay the foundation for artificial intelligence system of mineragraphy recognizing and processing in sinter ore.

(cf. *ISIJ Int.*, **48** (2008), 186)

Synthetic Samples Preparation to Identify Al_2O_3 Particles in Steel by Laser Ablation ICP Mass Spectrometry

A.G.COEDO et al.

The analytical technique based on laser ablation of the sample followed by Argon plasma excitation and mass spectrometry detection (LA-ICP-MS), was used to identify Al_2O_3 inclusions size and distribution on surface in iron samples. The main aim of the work is to evaluate different approaches for synthetic iron matrix samples preparation. Samples were made in four formats, from pure Fe powder (<25 μm) and Aluminum oxide with different ranges of particle size up to 100 μm: 1) metal samples, by melting in an induction furnace; 2) compressed pellets, by pressing at 50 ton cm^{-2}; 3) sintered compact samples, by sintering (1 050°C) and rolling (950°C) the compressed pellets; 4) beads (glass samples), by alkaline melting with lithium metaborate and sodium carbonate. The study includes the optimization of operating parameters; the evaluation of differences in ablation yield, by comparing the Fe signal intensities; and, the identification of Al_2O_3 particles in heterogeneous zones, by monitoring the Al time resolved signals. The optimized laser operating parameters were: laser pulse energy of 2.5 mJ pulse^{-1}, repetition rate of 10 Hz, and scanning speed of 3 μm s^{-1}. A good correlation between Al intensity peaks and mean size of particles was found for all types of produced samples, allowing estimate the size and the distribution of the Al_2O_3 particles in the sample surface.

(cf. *ISIJ Int.*, **48** (2008), 194)

Forming Processing and Thermomechanical Treatment

Analysis of Microstructure Evolution during Steckel Mill Rolling of AISI304 Stainless Steel

R.D.KNUTSEN et al.

The microstructural evolution in AISI304 austenitic stainless steel during Steckel mill rolling has been investigated. Particular emphasis is placed on the microstructural behaviour of the strip ends relative to the strip bulk. Good correlation between the development of hard ends that arise in the final strip and strip temperature and mean flow stress has been found by analysing mill log data. Measurement of the recrystallization kinetics under conditions that simulate Steckel mill rolling have shown that deformation temperatures below 950°C can lead to incomplete recrystallisation during the Steckel mill inter-pass. Predictions of the time to 50% recrystallisation ($t_{0.5}$) are used to quantify the recrystallisation kinetics of the strip ends.

(cf. *ISIJ Int.*, **48** (2008), 200)

Correlation between the Deformation and Post-deformation Softening Behaviours in Hot Worked Austenite

A.DEHGHAN.-MANSHADI et al.

The relation between the deformation and post-deformation softening behaviours of austenite is examined in a 304 stainless steel. This correlation has

been exploited in the modelling of hot rolling and it is argued here that the key to this understanding lies in the deformation structure. The latter is characterized in the present work by the fraction of dynamic recrystallization. The value of this fraction at the peak in the flow stress curve is found to decrease with increasing stress (*i.e.* with decreasing temperature and increasing strain rate). By contrast, the fraction of dynamic recrystallization at the strain corresponding to the point where post-deformation softening becomes strain independent is found to be *constant*. These observations are used to explain the nature of the important difference between the flow curve peak and the onset of strain independent post-deformation softening.

(cf. *ISIJ Int.*, **48** (2008), 208)

Effect of Pulse Electric Current Stimulation on the Microstructure, Mechanical Properties and Thermal Fatigue Behavior of Cast-hot-working Die Steel

H.LIN et al.

The microstructure variations in the heat affected zone (HAZ) of cast hot working die (CHWD) steels initiated by pulse electric current stimulation were investigated by the transmission electron microscopy (TEM) observation. Under the function of pulse electric current stimulation, some carbide particles segregating on the boundaries of neighboring lathing martensite in the original steel, were diffused as solid solution phases to the inner of martensite matrix. Compared with carbide agglomeration precipitating with irregular shape in the fatigued steel after 500 thermal fatigue cycles, the globularity of carbide was enhanced by degree and the interface between carbide and matrix was much improved in the corresponding electrostimulated steel. The X-ray diffraction analysis showed that the dislocation density was obviously increased in the HAZ when the application of pulse electric current through the original steel, especially for the stimulated specimen after thermal fatigue for 500 cycles. The reason was regarded as that the dislocation motion and multiplication were enhanced by the electro-dislocation interaction, Joule heating effect and thermal compressive stress under the function of pulse electric current stimulation. By the coexisting action of strengthening mechanisms by refining grain, increasing dislocation density and dispersively distributing nanosized carbide particles, the ultra tensile strength (UTS) of the HAZ was improved from 1 738 MPa in original state to 2 420 MPa by the stimulation of pulse electric current. Especially for the stimulated steel after thermal fatigue for 500 cycles, the UTS even reached 2 687 MPa. Pulse electric current stimulation played a strengthening role on CHWD steel material and inevitably improved the thermal fatigue behavior and prolonged the service lifetime of die material.

(cf. *ISIJ Int.*, **48** (2008), 212)

Surface Treatment and Corrosion

Nanostructured Surface Layer of Ti-4Al-2V by Means of High Energy Shot Peening

J.HAN et al.

A nanostructured surface layer was formed on the ends of TA17 bars by means of high energy shot peening (HESP). Microstructures in the plastic deformation layer were systematically characterized and analyzed by using optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM), microhardness measurement and X-ray diffraction (XRD). Based on the experimental observations and analysis, nanograins with an average size of 35 ± 5 nm were achieved on the top surface layer, the microhardness on the top surface is near twice that of the coarse-grained matrix. In terms of special metals materials, the stress and strain rate are critical for grain refinement in the process of surface self-nanocrystallization (SSNC). On the basis of discussion for microstructure in the plastic deformation layer, the grain subdivision mechanism of TA17 was drawn that twinning deformation transformed coarse grains into fine twinning lamellae at the low strain rate level, and the submicronic grains are broken down into randomly oriented nanograins by means of dislocation glide at high level of strain.

(cf. *ISIJ Int.*, **48** (2008), 218)

Numerical Simulation of Zinc Flow and Temperature Distribution in a Galvanizing Zinc Pot

H.S.PARK et al.

Zinc flows inside induction channel have been investigated as well as flows inside zinc bath. Lorentz force and heat have been obtained by detailed modeling of electro-hydrodynamics in the inductor channel. The Lorentz force gets added to momentum equations. Generated heat is utilized in energy equation. Flow vectors inside channel have great magnitudes of 540–200 cm/s range and directions from core to opposite. However molten zinc inlet has been clearly observed in the middle channel and outlets on two side channels. Two line speeds of 3.0 and 1.5 m/s have been adopted to see the effect of line speed. Flow pattern in the inside strip region was affected by line speed. The rest area of pot shows little difference. Temperature distribution was uniform over the entire bath within 1.3 degrees. The induction channel displayed an increase in temperature by approximately one degree Celsius compared to inside the zinc pot.

(cf. *ISIJ Int.*, **48** (2008), 224)

Environmental Influence on the Corrosion Rate of Steel Bars Embedded in Concrete

M.YOKOTA et al.

Investigation was carried out to verify the influence of temperatures an ambient environment, on the corrosion rate of steel reinforcement in concrete structures. Two concrete specimens, into which from an upper surface 10% sodium chloride solution permeated, were exposed outdoors. To evaluate the corrosion rate of steel bars embedded in concrete, the macro-cell corrosion current and the polarization resistance were measured regularly for more than 4 years, employing the AC impedance measurement. The macro-cell corrosion current and the polarization resistance of steel bars embedded in concrete were highly affected by temperature. It is found that the corrosion rate has increases linearly as 1/10 times against 1°C rise in temperature.

(cf. *ISIJ Int.*, **48** (2008), 230)

Transformations and Microstructures

Physical Model of Stress and Deformation Microstructures in AISI 304L Austenitic Stainless Steel Induced by High-current Pulsed Electron Beam Surface Irradiation

Q.GUAN et al.

AISI 304L austenite stainless steel was irradiated by a high-current pulsed electron beam (HCPEB) source in different process. The deformation microstructures were investigated by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The relationship between stress characteristic and the microstructures has been established. The current numerical simulations of the thermal-mechanical process of HCPEB treatment were also reviewed comparing with the present experimental results. Our experimental results suggest that the value of the stress induced by HCPEB is between 10^2–10^3 MPa or even larger. This stress results in the change of microstructure of the irradiated material in deeper region beneath the surface. According to the experimental results, a new physical model of the thermal-stress process and related modification mechanism as a result of HCPEB irradiation has been developed.

(cf. *ISIJ Int.*, **48** (2008), 235)

Social and Environmental Engineering

Magnetic Fixed-bed Column for Cr(VI) Removal from Aqueous Solution Using Schwertmannite

A.ESKANDARPOUR et al.

The fine particles of schwertmannite as an iron oxyhydroxide adsorbent has been suggested as a novel and strong Cr(VI) sorbent for treatment of Cr-contaminated industrial wastewater. The removal process was conducted in both batch and continuous trials. As a result of the batch experiments, the maximal adsorption capacity of the schwertmannite was obtained as 178 mg/g which was quite high amount in comparison with the usual applied Cr(VI) sorbents in the literatures. The continuous removal process involved a combination of a fixed bed column with a high gradient magnetic field which was firstly introduced as a novel designation of a fixed bed column to overcome the difficulties accompanied with the application of some especial fine particle adsorbents through the fixed-beds. The experimental results revealed that the magnetization force had a great function in this process to control the shape and the fitness of the bed during the sorption test as well as to simplify the experimental set-up.

(cf. *ISIJ Int.*, **48** (2008), 240)

Application of Hydrothermal Treatment on BF Slag and Waste Glass for Preparing Lubricant Materials in High Strain Rolling for Ultrafine-grained Steel Production

S.SATO et al.

In order to establish a high strain rolling process for the production of ultrafine-grained steels, a new lubricant showing stable biting between rolls and workpieces as well as a lubricating effect inside the hot rolls is required. We focused on glass materials for the stable biting property in view of their hardness and investigated the possibility of applying blast furnace (BF) slag and waste glass as the lubricant. The addition of a lubricating property to these glass materials was attempted by water introduction with a hydrothermal treatment, using the water release with heating that leads to a structural change inside the hot rolls. For that purpose, the hydrothermal treatment of the BF slag and waste glass was carried out, and the water release with re-heating was investigated. Furthermore, friction properties of the synthesized lubricants containing the hydrothermally treated materials were measured by a Timken extreme pressure tester at 373–1 173 K.

(cf. *ISIJ Int.*, **48** (2008), 245)