（＊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

A mathematical model of an impinging air jet on a water surface

M.ERESSON et al.

A fundamental mathematical model of the flow field and surface deformation caused by an impinging jet in a top blown reactor has been developed. The results have been validated against water model experiments. More specifically, the predicted penetration depth has been found to agree well with surface deformation measurements and predictions using analytical equations. Furthermore, the predictions of the location of a vortex have been found to agree fairly well with PIV measurements. Calculations were also done to compare the widely used standard k–ε model against the realizable extension of the standard k–ε model to calculate the turbulent conditions of the flow. It was found that the penetration depth caused by the impinging jet on the liquid surface is relatively unaffected by the choice of turbulence model employed. However, when the main re-circulation loop in the bath was investigated there was a clear distinction in the flow fields produced when the two different turbulence models were used.

(cf. *ISIJ Int.*, **48** (2008), 377)

Equilibrium constants and nitrogen activity in liquid metals and iron alloys

J.SIWKA

In the initial period of steel production with nitrogen as an alloy addition, from among the three thermodynamic factors, *i.e.* chemical composition, temperature and pressure, use was made of the first and the second factor only. Consideration given to the third factor created conditions for the realization of the "old" idea of steel ennoblement using nitrogen. An experimental setup for the investigation of the equilibrium state of chemical reactions in the gaseous phase–liquid metal system in the pressure range from 0.001 to 3.2 MPa and at temperatures not exceeding 2 423 K has been constructed and is presented in this paper. This setup relies on the levitation metal melting technique, whereby the ceramic crucible is eliminated and does not take part in the reaction phenomena. Intensive induction mixing of the liquid metal and the rapid cooling of samples in the experiment period provide the reproducibility of a given state through chemical analysis of the frozen samples of metal. The solubility of nitrogen in liquid iron, chromium, nickel, cobalt, vanadium and iron alloys in the pressure range 0.001 to 3.2 MPa at various temperatures, was determined. The determined characteristics made it possible to develop a thermodynamic model describing the solubility of nitrogen, temperature and chemical composition in a wide range of variation of these factors. The established nitrogen–nitrogen interaction reduces the effectiveness of nitrogen introduced to the liquid steel.

(cf. *ISIJ Int.*, **48** (2008), 385)

Kinetic of carbothermic reduction of MnO from high-carbon ferromanganese slag by graphite materials

J.SAFARIAN et al.

The kinetics of MnO reduction from a synthetic ferromanganese slag by different graphite materials was investigated using sessile drop wettability technique. It was found that the graphite substrates are not wetted by the slag drop at 1 450°C, 1 500°C and 1 600°C. On the other hand, processing the photos taken during the reduction revealed that the contact angle between the graphite substrates and the slag drop is not changing appreciably during slag reduction, while the changes in the slag drop volume are more significant. A new method was developed and applied to convert the changes in the slag drop volume to the MnO concentration and therefore the MnO reduction curves for different graphite substrates were extracted. The relationship between the density of slag and its MnO content was also studied. A new kinetic interpretation method was developed and a main differential equation for carbothermic MnO reduction from a slag drop in sessile drop method was obtained. This method was used to calculate the MnO reduction rate constants for different graphite materials considering the changes in the slag/carbon contact area. Multivariate analysis was also used to determine the possible relationships between the graphite properties and the MnO reduction rate.

(cf. *ISIJ Int.*, **48** (2008), 395)

Composition dependence of microstructures formed by phase separation in multi-component silicate glass

M.SUZUKI et al.

It has been investigated that the correlation between the phase separation and glass compositions in the SiO_2–CaO–MgO–Na_2O quaternary oxide glasses. The metastable miscibility gap and the spinodal region in the quaternary system have been evaluated from Gibbs energies in the metastable liquid phase, on the assumption that the glass in slag systems could be regarded as a super-cooled liquid. The microstructures corresponding to the phase separation in the glasses have been observed using transmission electron microscopy (TEM). Thermodynamic analyses and the experimental studies revealed the existence of a metastable phase separation including spinodal decomposition in the SiO_2–CaO–MgO–Na_2O system. Furthermore, it was found that the size of the decomposed microstructure depended on molar ratio of CaO to MgO in the initial glass composition.

(cf. *ISIJ Int.*, **48** (2008), 405)

Ironmaking

Analysis of drainage rate variation of molten iron and slag from blast furnace during tapping

M.IIDA et al.

Despite its importance in practical blast furnace (BF) operation, the dominant factors to control drainage rate or tapping time have not been well studied. In most cases, short tapping time has been attributed to rapid tap hole diameter enlargement. On the other hand, the experiential tendency about positive correlation between furnace hearth bottom temperature and drainage rate has been widely recognized.

In order to examine the dominant factors to control the liquid drainage rate or tapping time at BF, a simulative calculation model is introduced, where the liquid drainage path consists of coke particles packed layer (coke filter) and tapping hole and the overall drainage rate is determined as one of smaller fluid rate in coke filter or tapping hole. For calculating the fluid rate in coke filter, a hypothesis that liquid iron and slag in coke filter is driven toward the tap hole entry point consuming the coke particles, whose extent depends on molten iron C saturation degree and FeO fraction in molten slag, was introduced.

The calculation results present good matches with the observed tapping operation. This result can be explained by the two influences of low permeability zone formation or elimination at furnace hearth. Considering the two influences of low permeability zone formation, (1) to lower hearth bottom temperature and (2) to induce low C saturation of pig iron due to short traveling time in liquid pool to tap hole entry point, the simulation result conforms to the above mentioned experiential tendency.

(cf. *ISIJ Int.*, **48** (2008), 412)

Effect of high Al_2O_3 slag on the blast furnace operations

K.SUNAHARA et al.

Increasing the Al_2O_3 content in the blast furnace slag, the blast furnace operations tend to make troubles such as excess accumulation of molten slag in the blast furnace hearth and increasing pressure drop at the lower part of the blast furnace. So, it will be important to keep good slag fluidity at the blast furnace operations such as, drainage of tapping and keeping good permeability.

In order to clarify the effect of high Al_2O_3 slag fluidity on the blast furnace, high Al_2O_3 slag (20%) test operations of experimental blast furnace have been carried out. Investigation results of the test operation are as follows;

1) Slag MgO improves the hearth drainage rate at high Al_2O_3 slag operation.
2) Permeability of the dripping zone is improved by decreasing slag CaO/SiO_2, at high Al_2O_3 slag operation of the blast furnace.
3) It was verified that the slag drainage phenomena were able to described by the fluid model.
4) The optimum composition of high Al_2O_3 slag of the blast furnace is high MgO and low CaO/SiO_2.

(cf. *ISIJ Int.*, **48** (2008), 420)

Steelmaking

Numerical simulation of flow-induced wall shear stress to study a curved shape billet caster tundish design

V.SINGH et al.

Wall shear stress due to flow of the molten steel in the tundish is one of the factor for erosion of refractory walls which decides sequence length of a

tundish. The flow-induced shear stress on the wall of a six strand curved type billet caster tundish has been computed by a 3-D mathematical model. The location of predicted peak wall shear stress was found to be same as observed in the plant after a sequence. Different design parameters of the tundish such as wall inclination angle, curvature radius, and tundish width are studied by analyzing the flow-induced wall shear stress. The role of a pouring chamber is assessed with respect to the wall shear stress. It was found that vigorous circulation around the inlet stream from shroud plays a major role in deciding the extent of the wall shear stress. Use of pouring chamber resulted in lesser wall shear stress than that of a bare tundish. The peak shear stress was found to be decreasing as any of the design parameters increased within a range. A modification in design parameter of the tundish can reduce the wall shear stress, thus may help to improve the sequence life of the tundish.

(cf. *ISIJ Int.*, **48** (2008), 430)

Effect of temperature on oxygen activity during ladle treatment

J.BJÖRKLUND et al.

The effect of temperature on oxygen activity in steel was studied in plant trials where temperature and oxygen activity were measured at two depths and at the same time during different parts of ladle refiining. The results show that large temperature grdients exist towards the surface of the steel melt for the sampling occasion when no slag is present on the steel surface, as can be expected. It was also observed that the oxygen activity is higher in the lower measurement position than in the upper during the majority of the ladle refiining. This is explained b the oxygen activity's temperature dependence. By using the data from this study and previously reported plant trials it was shown that Si–SiO_2 or Al–Al_2O_3 equilibrium controls the oxygen activity.

(cf. *ISIJ Int.*, **48** (2008), 438)

Casting and Solidification

Mechanism of heat transfer reduction by crystallization of mold flux for continuous casting

H.NAKADA et al.

The mechanism by which crystallization of mold flux reduces the heat transfer between the steel shell and the mold has been investigated from the viewpoint of physical properties and characteristics of mold flux and air gap on the basis of a heat transfer model involving conduction and radiation processes. It has been found that, in mold fluxes for medium carbon steel, the reflectivity of the crystalline slag layer formed in mold flux film is an efficient factor for further reducing the total heat flux in the film. The heat transfer reduction based on this finding would be possible according to the following mechanism: Crystallization of mold flux film increases the reflectivity of the crystalline slag layer in the film owing to enhanced scattering of light by introduction of crystal grain boundaries, and thereby more radiation energy returns from the crystalline slag layer to the steel, leading to reduction in the total heat flux across the film.

(cf. *ISIJ Int.*. **48** (2008), 446)

Description of the hypo-peritectic steel solidification under continuous cooling and crack susceptibility

J.J.R.MONDRAGÓN et al.

This study describes the phase evolution during solidification under continuous cooling conditions o a hypo-peritectic multicomponent steel. Additionally, the mechanical behavior and dimensional variation of the solid–liquid skin were evaluated by using mathematical expressions reported in the literature as a function of the proportion of phases and solute distribution respectively. The crack susceptibility of the solid–liquid skin depended on the proportion of phases and it occurred in two solid fraction regions, independently of the cooling rate. For the region exhibiting the lowest solid fraction values this susceptibility was associated to γ phase, while at the highest solid fraction values it was related to δ phase.

At the end of the peritectic transformation the highest contraction observed can be considered as an additional contribution to the crack susceptibility in the solid fraction range of 0.92–0.98. The significant microsegregation of Mn observed for high cooling rates promotes a change in the solidification mode, from a hypo-peritectic mode into a hyper-peritectic mode and the expansion of solid formed from the remaining liquid.

(cf. *ISIJ Int.*, **48** (2008), 454)

Instrumentation, Control and System Engineering

Evaluation of dislocation structure in tensile and fatigue deformed steels by magnetic measurement

K.YAEGASHI

Magnetic properties are compared with total dislocation density that considered the dislocation structure change comprehensively in tensile and fatigue deformed commercial steels. Coercive field increases little with the fatigue cycles and seems to be saturated in the middle and last stages of metal fatigue. The coefficient of magnetic susceptibility c increases over all stages of the fatigue tests and is sensitive to degradation in comparison with H_C. These properties are influenced from total dislocation density, and independent on deformation way. The magnetic-structure-sensitive properties would be useful for evaluation of dislocation structure change, and applied nondestructive evaluation method with development of the correct B–H curve measurement way.

(cf. *ISIJ Int.*, **48** (2008), 461)

Forming Processing and Thermomechanical Treatment

Effect of O_2 in heating atmosphere on hydraulic descaling in hot rolling of low carbon steel

V.V.BASABE et al.

Low carbon steel was oxidized over the temperature range 1 050–1 250°C in O_2–CO_2–H_2O–N_2 gas mixtures. The oxidation times were 15–120 min, and the scales were 130–2 000 μm thick. The experimental parameters were chosen to approximate scale formation under conditions similar to those of reheating furnaces in hot strip mills. In the hydraulic descaling tests, two modes of scale removal were observed. In the first mode, observed in classical three-layer scales that developed an inner porous layer with low or medium porosity, the horizontal undercutting occurred at the boundary of the inner porous layer and dense scale. The second mode was observed in classical three-layer scales that developed an inner porous layer with high porosity, and in crystalline scales. In the second mode, the horizontal undercutting occurred at the first plane of large pores relative to the scale/steel interface. A rise in the concentration of free oxygen resulted in an increase in thickness of the residual scale at 1 050°C. At 1 100°C and 1 150°C, the increase in residual scale thickness with increasing free oxygen was significant in the initial 60 min of oxidation; after this period of time the differences in the thickness of the residual scale became smaller. At higher temperatures, the influence of free oxygen in the residual scale thickness was small at 1 200°C and negligible at 1 250°C. In general, the experiments showed that scale morphology controlled the removability of scale.

(cf. *ISIJ Int.*, **48** (2008), 467)

Recrystallization and grain growth behavior in severe cold-rolling deformed SUS316L steel under anisothermal annealing condition

N.HIROTA et al.

Ultrafine grained microstructure seems difficult to be obtained in austenite stainless steel by hot rolling process because the steel has a high recrystallization temperature and high grain growth rate. Instead of severe plastic deformation at medium temperatures, anisothermal annealing of cold-rolled steel could be an effective way to obtain the ultrafine microstructure in the steel. In order to clarify the recrystallization and grain growth in SUS316L stainless steel in anisothermal annealing condition, variations of hardness and average grain size of the steel at annealing temperatures ranging from 1 073 to 1 223 K and heating rates in the range of 0.031–9.3 K/s were systematically investigated, and the results were summarized in contour maps. The recrystallization finish temperature was recognized by a hardness criterion, which shows a linear relationship with the logarithm of the heating rate. Moreover, the average grain size at the critical temperature is approximately 2.2 μm at low heating rates, but decreases quickly with the increase of heating rates above 1 K/s. A proposed grain growth kinetics equation for anisothermal annealing is applied in the present investigated SUS316L steel. The proportional term, *i.e.*, $\Pi=(D^n-D_0^n)/(\Gamma_f-\Gamma_i)$, in the equation is calculated and is found to follow the equation $\Pi=K\cdot\exp(0.5/\theta)$. Meanwhile, the grain growth exponent, n, for the anisothermally annealed SUS316L steel is also determined and is found to lie between 2.5 and 3.0. On the other hand, EBSD analysis of the evolved microstructure at different heating rates

indicates that low heating rate caused partial recrystallization with preferred orientations at the recrystallization finish temperature, while high heating rates above 1 K/s induced the homogeneously nucleated recrystallization microstructure with random orientations and a lognormal type grain size distribution.

(cf. *ISIJ Int.*, **48** (2008), 475)

Welding and Joining

Metallurgical and mechanical properties of fusion zones of laser welded TRIP steels

M.XIA et al.

Transformation induced plasticity (TRIP) steels are a promising solution for the production of cars with low body mass because of the combination of high strength and high plastic strain capacity that they offer. Si and Al are two important alternatives for alloying of TRIP steels in order to suppress carbide precipitation in the bainite holding temperature range during steel manufacture. Weldability of TRIP steel is one of the key factors governing its application in auto industry. In this paper, Al-alloyed TRIP steel was investigated with the diode laser welding process in terms of fusion zone metallurgical and mechanical properties, with Si-alloyed TRIP steel also included for comparison. It was found that the fusion zone of the Al-alloyed steel has a multiphase microstructure, containing skeletal ferrite, bainitic ferrite, martensite and retained austenite of two different morphologies. In contrast, the Si-alloyed steel fusion zone consists almost entirely of martensite. The high martensite content results in low fusion zone ductility in the Si-alloyed steel, only providing half the tensile elongation of the Al-alloyed steel. The Si-alloyed steel shows a greater decrease of the strength–ductility balance (ultimate tensile strength times elongation) due to welding, *i.e.*, 62.9% compared to 45.2% for the Al-alloyed steel in quasi-static tensile testing. High strain rate tensile testing with a Hopkinson Bar apparatus shows no significant effect of strain rate on the fusion zone ductility for either steel. The fusion zone of the Al-alloyed steel does not exhibit a detectable TRIP effect probably due to the low carbon content in the retained austenite. Al and Si are both relevant as agents to suppress cementite precipitation, but they are found to exert very different influences on steel weldability.

(cf. *ISIJ Int.*, **48** (2008), 483)

Effect of autogenous arc welding processes on fatigue crack growth behaviour of ferritic stainless steel joints

V. BALASUBRAMANIAN et al.

The present investigation is aimed at to study the effect of autogenous arc welding processes on fatigue crack growth of the ferritic stainless steel conforming to AISI 409M grade. Rolled plates of 4 mm thickness were used as the base material for preparing single pass butt welded joints. Tensile, impact and fatigue properties, micro hardness, microstructure and fracture surface morphology of the continuous current gas tungsten arc welded, pulsed current gas tungsten arc welded and plasma arc welded joints were evaluated and the results are compared. From this investigation, it is found that plasma arc welded joints of ferritic stainless steel showed superior fatigue performance compared with continuous current gas tungsten arc welded and pulsed current gas tungsten arc welded joints and this is mainly due to the superior mechanical properties, preferred microstructures in the fusion zone region and favourable residual stress field in the fusion zone region.

(cf. *ISIJ Int.*, **48** (2008), 489)

Surface Treatment and Corrosion

A prediction model for hydrogen induced cracking in a prestressed wire with a fracture analysis

T.CHO et al.

This paper deals with the Hydrogen Induced Cracking (HIC) behavior of high strength tendon wires of a prestressed structure, exposed to aggressive environments. A decoupling technique has been suggested to evaluate crack propagations in a wire section, driven by the hydrogen diffusion. By the proposed decoupling technique, three dimensional crack propagations can be modeled effectively by two 2-dimensional finite element models, one for the fracture analysis of a round bar wire in a longitudinal section, and the other for a hydrogen diffusion model in a horizontal section. Elastic and bi-linear elastic–plastic finite element analyses have been carried out for the evaluation of crack propagations in wires of tendon. A finite element program is developed for the hydrogen diffusion-stress analyses of wires. The decoupled analysis results have been compared with available test results, and showed improved results than the linearly assumed analytical equations suggested by Forman *et al.*

(cf. *ISIJ Int.*, **48** (2008), 496)

Electrodeposition of composites of zinc with vanadium oxide from sulfate solutions

H.NAKANO et al.

Electrodeposition of Zn with V was examined from optionally agitated sulfate solutions containing Zn^{2+} and VO^{2+} at pH 0–3 and 40°C under galvanostatic conditions. XPS spectra of the deposits showed that V was present in the deposited Zn in the form of its oxide, formed by hydrolysis of V ions. The V content of the deposits increased with increasing pH of the solution and increasing current density. These conditions appear to accelerate the hydrolysis of V ions by means of an increase in hydrogen evolution in the cathode layer. SEM and EPMA studies of the deposits showed that the V in the deposits was segregated at the edges of layered platelet crystals of Zn. Agitation of the electrolyte decreased the V content of the deposits but reduced the segregation of V oxide. Anodic polarization curves for dissolution of Zn in 3% NaCl solution were polarized by codeposition of V oxide with Zn for V contents of <5 mass%. The corrosion current densities of deposits obtained from agitated solutions were smaller than those from un-agitated solutions.

(cf. *ISIJ Int.*, **48** (2008), 506)

Transformations and Microstructures

Mobility analysis of the austenite to ferrite transformation in Nb microalloyed steel by phase field modelling

Y.TAKAHAMA et al.

It is well-known that the solute drag effect due to dissolved Nb and the pinning effect due to NbC in Nb microalloyed steel cause retardation of the grain growth during austenitisation and of the transformation during cooling. These effects strongly depend on the austenitisation-temperature. But there is little numerical research on both effects simultaneously so far. In this study the mobility behaviour during austenite (γ) to ferrite (α) transformation was investigated by phase field modelling, showing that the α/γ boundary velocity during cooling increases with increasing austenitisation-temperature. These phenomena are caused by both pinning and solute drag effects. The effect of pinning decreases as the austenitisation-temperature increases because NbC dissolves with austenitisation treatment at high temperature. On the other hand, the strength of the solute drag effect is the highest for intermediate austenitisation-temperature, where the α/γ boundary velocity during cooling is in the intermediate range, and the strength is determined by the effects of both the concentration of dissolved Nb atoms and the α/γ boundary velocity. These features are quantitatively discussed from the simulation results.

(cf. *ISIJ Int.*, **48** (2008), 512)

Mechanical Properties

Structure, mechanical properties and wear resistance of high-vanadium cast iron

M.KAWALEC et al.

A series of melts with carbon content 1.38–4.16% and that of vanadium 5.25–15.50% was made. The X-ray diffraction of the examined alloys revealed the presence of three phases, *i.e.* ferrite, alloyed cementite, and VC_x carbide. The relationships between the content of carbon and vanadium corresponding to eutectic structure (the eutectic line) as well as the degree of eutectic saturation S_c were determined. Besides eutectics, the high-vanadium cast iron holds the following constituents in its matrix: alloyed ferrite, granular pearlite, and lamellar pearlite as well as a mixture of alloyed ferrite+granular pearlite, granular pearlite+lamellar pearlite. The results show that passing from ferritic matrix through granular pearlitic and to lamellar pearlitic matrix, hardness HB, tensile strength R_m, and yield strength $R_{0.2}$, increases while plastic properties of alloys represented by elongation A_5 decreases. The wear behaviour of alloys was tested in two different modes "specimen-abrasive paper" test (P1) and "specimen-counterspecimen" test (P2). The results obtained in test P1 are following: a) alloys with ferritic matrix and of the lowest hardness (182–189 HB) are characterised by the lowest abrasion wear resistance (s=3.14–3.93 mg/m), b) in alloys with a pearlitic matrix and hardness in the range of 387–416 HB the abrasion wear resistance is comparable to that of

Hadfield cast steel (about $s=2$ mg/m) and c) cast iron with lamellar pearlite+granular pearlite matrix and hardness 322 to 401 HB gives the highest abrasion wear resistance of $s=0.24$–0.62 mg/m. In general, it can be stated that the abrasion wear in test P2 is higher than in test P1.

(cf. *ISIJ Int.*, **48** (2008), 518)

Heterogeneous deformation behavior studied by *in situ* neutron diffraction during tensile deformation for ferrite, martensite and pearlite steels

S.Morooka et al.

Tensile behavior was investigated by using *in situ* TOF neutron diffraction comparatively for ferritic steels; ferrite (F), as-quenched martensite (QM), tempered martensite (TM) and pearlite (P) steels. Changes in lattice spacing, diffraction intensity and FWHM with increasing of the applied stress were measured. Preferential plastic flow takes place depending on crystal orientation, so that intergranular stresses are yielded due to the misfit plastic strains in differently oriented [*hkl*] family grains for steel F, in blocks for the other steels. Because of the existence of cementite in steels TM and P, phase stresses are superposed upon the intergranular stresses. When the averaged phase strain is subtracted from the measured lattice strain, the trend in generation of intergranular strain in steel TM is similar to that observed in steels F and QM, while that in steel P differs from the other steels. The changes in [*hkl*] diffraction intensity and FWHM with tensile deformation are similar in steels F, TM and P, while those in steel QM are different from the others. FWHM decreases with tensile deformation suggesting the decrease in dislocation density in steel QM. That is, dislocations induced during martensitic transformation move preferentially and are annihilated by coalescence of dislocations with different signs in the beginning of deformation and hence transformation induced dislocation structure changes to deformation induced one that shows lower dislocation density but higher resistance to tensile flow. The preferential movement of transformation induced dislocations in steel QM leads to a different texture evolution which is recognized from the change in diffraction intensity with tensile deformation.

(cf. *ISIJ Int.*, **48** (2008), 525)

Physical Properties

Effect of cerium content on the magnetic properties of non-oriented electrical steels

C.-K.Hou et al.

The effects of cerium content in the range of 0–0.022 wt%, on the microstructure, texture and magnetic properties of four non-oriented electrical steels have been studied. After final annealing, grain size increased with increasing cerium content and reached a maximum value in the steel with 0.011 wt% cerium. Furthermore, steel containing 0.003 wt% cerium had the strongest (110)⟨001⟩ texture among the steels. In the steel with the same cerium content, the intensity of (111)⟨*uvw*⟩ fiber texture decreased with decreasing hot finishing rolling temperature and increasing hot band annealing temperature. Under the same processing conditions, flux density slightly increased with increasing cerium and reached a maximum value in the steel with 0.003 wt% cerium. For steel with the same cerium content, flux density increased with increasing hot band annealing temperature and decreasing hot finishing rolling temperature. Conversely, core loss decreased with increasing cerium content and reached a minimum value in the steels containing 0.003 wt% cerium. For steel with the same cerium content, core loss decreased with increasing hot band annealing temperature and decreasing hot finishing rolling temperature. Steel with 0.003 wt% cerium obtained the best magnetic properties, predominantly through the development of favorable texture and optimum grain size.

(cf. *ISIJ Int.*, **48** (2008), 531)

Social and Environmental Engineering

Technical feasibility study of waste heat transportation system using phase change material from industry to city

A.Kaizawa et al.

A waste-heat transportation system that uses a phase change material (PCM)—the so-called *transheat (TH) system*—is considerably attractive from the viewpoint of saving energy because manufacturing industries such as the steelmaking industry continue to emit high-temperature waste heat. The aim of this paper is to study the feasibility of the TH system from three viewpoints—energy requirement, exergy loss and CO_2 emissions—which affect the heat source and heat storage materials in the TH system. The TH system, which recovers waste heat and supplies hot or cold water, is comparatively evaluated under reasonable assumptions such as the temperature of the waste heat is 200°C and that of the supplied water is 50°C or 7°C, the transportation distance is 20 km and the laden weight of the container is $2.4\cdot10^4$ kg (weight of the PCM=$1.75\cdot10^4$ kg; weight of the heat transfer oil=$2.5\cdot10^3$ kg). The following results are obtained: The latent heat of erythritol supplies the largest amount of heat, 5.31 GJ at 50°C, in the TH systems. For supplying hot water at 50°C, the energy requirement of the TH system with erythritol is 7.7%, exergy loss is 8.1% and CO_2 emission is 20.2% as compared to those of the conventional system with kerosene on site. For supplying cold water at 7°C, the energy requirement of the TH system with erythritol is 12.0%, exergy loss is 12.0% and CO_2 emission is 26.6% as compared to those of a conventional absorption chiller that uses natural gas as the heat source.

(cf. *ISIJ Int.*, **48** (2008), 540)

Substance flow analysis of manganese associated with iron and steel flow in Japan

K.Nakajima et al.

This study conducts the substance flow analysis (SFA) of Manganese (Mn) with regard to the iron and steel cycle, which accounts for 95% of the demand for Mn, along with the data collection and assessment of material/substance flow; as a result, an efficient material cycle system is formulated for the Mn flow.

The main conclusions are (1) Mn charged as iron ore and the Mn content of other ferrous raw materials reached 266.2×10^3 t-Mn of which 208.9×10^3 t-Mn was discharged as pig iron and 55.4×10^3 t-Mn as blast furnace slag in the ironmaking process, and (2) 530.7×10^3 t-Mn was discharged as steelmaking slag and 577.6×10^3 t-Mn was charged in the secondary refining process as Ferro-Mn, Si–Mn, and metal Mn for the purpose of adding them as constituents of alloy in the steelmaking process.

(cf. *ISIJ Int.*, **48** (2008), 549)