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Transformations and Microstructures

Computer simulation of microstructure evolution in low carbon sheet steels (Review)

M.MILITZER

Models of microstructure evolution in steels are reviewed. The emphasis of the review is on low carbon sheet steels both hot-rolled and cold-rolled and annealed. First the state-of-the-art on industrial microstructure process models is presented. The individual model concepts for grain growth, recrystallization, precipitation and phase transformations are briefly discussed. The development from empirically-based models to physically-based models is identified as a key issue to have increased predictive capabilities for these models over a wider range of steel grades and operational conditions. The challenges in the development of the next generation of models are delineated. In particular, new aspects of microstructure evolution associated with novel processing routes and advanced high strength steels are evaluated. Further, the majority of the currently employed models are on the macro-scale but future microstructure models will increasingly be meso-scale models that predict actual microstructures rather than a number of average parameters (*e.g.* grain size, fraction transformed) to describe microstructure evolution.

(cf. *ISIJ Int.*, **47** (2007), 1)

Fundamentals of High Temperature Processes

Thermodynamics of titanium and oxygen dissolved in liquid iron equilibrated with titanium oxides

J-J.PAK et al.

The equilibrium relation of Ti and O dissolved in liquid iron saturated with solid titanium oxides was measured in the temperature range of 1 823 to 1 923 K. Pure Ti_2O_3(s) phase was identified as the equilibrium deoxidation product for iron melts containing 0.25–4.75 mass% Ti. Using Wagner's formalism, the present results were thermodynamically analyzed to determine the equilibrium constant of Ti deoxidation reaction for the formation of pure Ti_2O_3(s) and the first- and second-order interaction parameters between Ti and O given as follows in the temperature range of 1 823 to 1 923 K.

$$2\underline{Ti}+3\underline{O}=Ti_2O_3(s) \quad (0.25<\text{mass\% Ti}<4.75)$$

$$\log K_{Ti_2O_3}=44\,238/T-13.0$$

$$e_O^{Ti}=-1\,642/T+0.3358, \quad e_{Ti}^{O}=-4\,915/T+1.005$$

$$r_O^{Ti}=0.0385, \quad r_{Ti}^{O}=-0.355$$

The equilibrium titanium oxide phase was identified as Ti_3O_5(s) for iron melts containing 0.0012–0.25 mass% Ti at 1 873 K. The equilibrium constant of Ti deoxidation reaction for the formation of pure Ti_3O_5(s) were estimated as follows.

$$3\underline{Ti}+5\underline{O}=Ti_3O_5(s) \quad (0.0012<\text{mass\% Ti}<0.25)$$

$$\log K_{Ti_3O_5}=72\,813/T-21.32$$

The activity coefficient of Ti in liquid iron at infinite dilution, $\gamma^{\circ}_{Ti(s)}$ was assessed as 0.011, 0.014 and 0.018 at 1 823 K, 1 873 K and 1 923 K, respectively.

(cf. *ISIJ Int.*, **47** (2007), 16)

Calciothermic reduction of zirconium oxide in molten $CaCl_2$

A.M.ABDELKADER et al.

The reduction of zirconium dioxide using liquid calcium and molten calcium chloride was investigated. The study focusing on the influence of reductant amount, reaction time, $CaCl_2$ amount, and temperature on the reduction process. Zirconium powder with oxygen content less than 800 ppm was obtained at 1 100°C after 3 h and by using two times the theoretical amount of Ca and four times that of $CaCl_2$. The reduction reaction of ZrO_2 was found to be multi steps process through the formation of intermediate phase $CaZrO_3$. The morphology of the obtained zirconium was observed to be highly affected by the reaction temperature.

(cf. *ISIJ Int.*, **47** (2007), 25)

Dissolution of dense lime in molten slags under static conditions

S.H.AMINI et al.

Static dissolution of CaO into a $CaO–SiO_2–Al_2O_3$ slag with fluxing agents (fluorspar, ilmenite and nepheline syenite) was studied using two experimental techniques. In one method, the slag was packed into dense CaO crucibles, and heated to 1 500°C/1 600°C. After reaction, the crucible was air cooled and cross-sectioned. In the second technique, slag with a piece of lime was heated in a platinum capsule. The development of the Ca_2SiO_4 phase at the lime/slag interface and the CaO dissolved in the slag from the lime specimen were examined by Electron Probe Micro Analysis and Scanning Electron Microscopy. Ilmenite and nepheline syenite were found to be effective substitutes for fluorspar, increasing the CaO dissolution rate in the slag.

(cf. *ISIJ Int.*, **47** (2007), 32)

Evaluation of the surface tension of ternary silicate melts

M.NAKAMOTO et al.

A thermodynamic model for determining the surface tension of molten ionic mixtures derived by considering the ionic radii was extended to ternary silicate melts. The composition dependence of the surface tensions of molten silicates in ternary systems, was reproduced by the present model using surface tension information, the molar volumes of pure oxides, as well as the anionic and cationic radii of the component oxides in the system.

(cf. *ISIJ Int.*, **47** (2007), 38)

Crystallization behaviors concerned with TTT and CCT diagrams of blast furnace slag using hot thermocouple technique

Y.KASHIWAYA et al.

Currently, the most of slags are recycled and reused by taking the advantages of the feature of respective slags (*e.g.* the BF slag is used for cement and roadbed material, LD slag is also used for the roadbed material and marine resources, *etc.*). The quality and quantity of recycle of slags changed greatly within recent ten years and it will be expected as an important resource in the future. Whereas there is a remained possibility on the recycle of slags, most of slags have a high temperature more than 1 500°C, when it was exhausted.

In general, there are two cooling processes adopted into the slag treatment, one is an air-cooling process and the other is a water quenching process. However, those slag cooling processes does not utilize the sensible and the latent heat related to high temperature melt. If there were a TTT (Time-Temperature-Transformation: isothermal transformation) diagram and a CCT (Continuous-Cooling-Transformation: continuous cooling curve) diagram, the property of the final slag could be estimated by the designed cooling path. Furthermore, it could be possible or easier to recover the sensible and the latent heat through a given cooling path.

In the present study, using SHTT (Single Hot Thermocouple Technique), TTT and CCT diagrams of BF slags were measured. Crystallization behavior in the TTT and CCT diagrams of BF slag were clarified by XRD analysis, SEM observation and EDS analysis together with the *in situ* observation. Crystal phases in the TTT diagram for BF slag used were Gehlenite ($2CaO\cdot Al_2O_3\cdot SiO_2$) and Merwinite ($3CaO\cdot MgO\cdot 2SiO_2$). The Merwinite precipitated faster than the Gehlenite. The nose position of Merwinite was 4 s at 1 090°C and the nose of Gehlenite was 8 s at 1 230°C. CCT diagram had wider glass region than TTT diagram and the temperature of crystal region decreased to 1 340°C at 1 000 s and 1 160°C at 14 s.

(cf. *ISIJ Int.*, **47** (2007), 44)

Ironmaking

The microstructure of the pig iron nuggets

B.ANAMERIC et al.

The pig iron nugget process (referred to as the Iron Technology Mark 3, or ITmk3, process by Kobe Steel) was developed as an alternative to the traditional blast furnace process. Throughout this process self reducing–fluxing dried greenballs are reduced and smelted in to nuggets of metal. The objective of this research was to produce pig iron nuggets at laboratory scale, then characterize and compare them with the blast furnace pig iron. Pig iron nuggets were characterized utilizing apparent density measurements, optical microscopy, scanning electron microscopy with energy dispersive spectroscopy, and bulk chemical analysis. It was determined that pig iron nuggets had high apparent density (6.7–7 g/cm^3); had a high iron content (95–97%); and exhibited microstructures similar to white cast iron, which is essentially the same as pig iron from a blast furnace.

(cf. *ISIJ Int.*, **47** (2007), 53)

Effect of carbonisation conditions on mineral matter in coke)

M.GRIGORE et al.

The mineral phases present in coke contribute to

coke degradation in the blast furnace. The mineral phases in coke are developed during coal carbonization process. Four Australian bituminous coals have been selected. Sub-samples from each coal were carbonized in three ovens of different capacity, and the carbonization parameters were also different. The mineral phases in cokes were identified in the low temperature ashed samples using X-ray diffraction technique. Amorphous alumino-silicate was the dominant phase in all cokes but the composition of the crystalline mineral phases varied to a great extent between cokes prepared from the same parent coal but in different ovens.

(cf. *ISIJ Int.*, **47** (2007), 62)

Prediction of iron ore pellet strength using artificial neural network model

S.Dwarapudi et al.

Cold Compression Strength (CCS) is an important property of iron ore pellets that are used for the production of DRI from shaft furnace or for use in blast furnace. CCS is one of the control parameters during the pellet production and it is supposed to be closely monitored to control the process. In order to develop control-strategy, an Artificial Neural Network model has been developed to predict CCS of pellets in straight grate indurating machine from 12 input variables *viz.* feed rate of green pellets, bed height, burn through temperature, firing temperature, specific fuel gas consumption; bentonite, moisture and carbon content in green pellets; Al_2O_3, MgO, basicity and FeO in fired pellets. CCS was found to be more sensitive to variation in Bentonite, basicity, FeO and Green pellet moisture. Generalized Feed Forward neural network with back propagation error correction technique was successfully used to predict the CCS. The predicted results were in good agreement with the actual data with less than 3% error.

(cf. *ISIJ Int.*, **47** (2007), 67)

Steelmaking

Behavior of top-blown jet under reduced pressure

I.Sumi et al.

In steelmaking, the top-blown oxygen jet is used in many different refining processes and its behavior is therefore an important factor in steel refining. Numerous studies have been conducted on jet behavior under atmospheric pressure conditions; however, its behavior under reduced pressure for vacuum refining processes is still not fully understood.

In this study, jet behavior under reduced pressure was investigated by measuring the dynamic pressure of the jet. Also, numerical simulation, which was used for jet simulation in recent studies, was carried out to clarify the details of the jet behavior. The simulated results were compared with the measured data and the numerical simulation method was validated.

As a result, the jet behavior was modeled using the numerical simulation, and the detailed effects of ambient pressure on the jet behavior were clarified. The potential core of the jet lengthened as the ambient pressure decreased, indicating that jet attenuation under reduced pressure is smaller than that under atmospheric pressure. Using this model, the effect of the nozzle shape on the post combustion behavior of the actual RH top-blown process could be explained.

(cf. *ISIJ Int.*, **47** (2007), 73)

Casting and Solidification

Development of flow field and temperature distribution during changing divergent angle of the nozzle when using swirl flow in a square continuous casting billet mould

S.Kholmatov et al.

Recently, positive effects of swirl flow have been investigated, related to specific billet moulds with particular divergent angles in the immersion nozzles.[1–7] Literature review showed that a systematic study of changes in the divergent angle in the immersion nozzle for continuous casting moulds had not been carried out. Therefore, in the present work we aim to investigate the development of flow field and temperature distribution inside the mould and on the meniscus while changing the divergent angle of the immersion nozzle. Swirl flow was used in the nozzle and the liquid entered a 3D square billet mould. Both physical and mathematical modelling was carried out to simulate nine different divergent angles between 0 and 160°. The overall results of the study showed that a change in divergent angle has an effect on the flow pattern as well as the temperature distribution of the liquid steel in the mould.

More specifically it was found that in the case of 100° divergent angle nozzle billet we can observe a major shift of lower circulation compared to that of the 80° nozzle billet. Furthermore, a noticeable increase of the temperature near the meniscus, for a square billet, and radial velocity component, for a round billet, was found when using the 100° divergent angle nozzle compared to the 80° divergent angle nozzle. Additionally, a uniform velocity and heat distribution was observed within a distance of 200 mm below the nozzle exit for nozzle outlets with 100° divergent angles and larger.

(cf. *ISIJ Int.*, **47** (2007), 80)

Fluid flow in a four-strand bloom continuous casting tundish with different flow modifiers

L.Zhong et al.

Fluid flows in a four-strand tundish for bloom continuous casting have been investigated with physical modeling and mathematical simulation methods. The liquid steel flow velocity fields in the former tundish and the optimal one with a turbulence inhibitor and newly-designed baffles were numerically calculated and the flow characteristics in the two cases and other tundish configurations were measured in the physical modeling. The results in the physical modeling experiments showed that large difference in the Residence Time Distribution (RTD) curves of two outlets in one side of the former configuration tundish existed. It was found from the numerical calculation of the velocity fields in the tundishes that with the former tundish configuration velocities and turbulent degree of the liquid steel flow in the impact zone of the tundish were large due to the high velocities of liquid steel from the long shroud of the ladle, which caused in lining corrosion and slag entrapment due to the surface eddies. Asymmetric velocity field in the tundish with the former baffles formed and short circuit flow existed in one side of the four-strand tundish. For the optimal configuration of the tundish with a turbulence inhibitor and newly-designed baffles, very similar RTD curves of the two outlets in the same side of the tundish were achieved. The velocities and turbulent degree in the impacting zone of the tundish were depressed and quiet and symmetric molten steel flow was obtained. Eddies on surface and short circuit flow in the optimal tundish disappeared. Such improvement of liquid steel flow in the tundish would increase the ability of inclusion removal. Turbulence inhibitors should be used with other well-designed flow control devices for effective improvement to fluid flow characteristics in tundishes.

(cf. *ISIJ Int.*, **47** (2007), 88)

The effect of mould flux properties on thermo-mechanical behaviour during billet continuous casting

R.Saraswat et al.

During continuous casting mould powder forms a pool of liquid flux which infiltrates into the solidifying shell/mould gap and forms a flux film containing liquid and/or solid layers. Subsequent crystallisation of the film results in the formation of an air gap at the mould wall. An air gap can also be formed by the shrinkage of the solidified shell. In practise, no air gap is formed by shell shrinkage in the upper mould since molten flux will flow immediately into and fill any gap formed. However, in the lower mould, if the shell temperature falls below the break temperature of the flux there is no liquid to fill any gap formed by shell shrinkage and hence an air gap can form. A model was developed which determines the effect of the various layers (including the air gap) on the horizontal heat transfer between shell and mould. A fully coupled, heat transfer/stress analysis was used to calculate: (i) the thickness of the various layers of the flux film; (ii) horizontal heat flux; and (iii) the resultant stress in the solidified shell.

The model predicted that: (a) the hoop stress increased as the interfacial thermal resistance decreases (*i.e.* the heat flux increases); (b) the maximum hoop stress at the exit decreased with increasing flux film thickness; (c) the ferro-static pressure tended to hinder the formation of an air gap at mid-face positions whereas in the corners the thicker shell tended to counteract the ferro-static pressure resulting in air gap formation; (d) the thickness of the liquid film at various positions in the mould was computed for fluxes with optimum break temperatures to determine if they provided liquid lubrication throughout the mould; and (e) the maximum stress occurred in the corner when casting with mould fluxes but at the mid-face when using oil.

(cf. *ISIJ Int.*, **47** (2007), 95)

Instrumentation, Control and System Engineering

Direct width control systems based on width prediction models in hot strip mill

C.J.PARK et al.

In this paper, a width control system is proposed to obtain the desirable width margin of a strip in the rolling process of the hot strip mill. A simplified FEM (Finite Element Method) based width prediction model (WPM) is developed to compute the width spread at each stand. A neural network based error correction model (ECM) is also introduced to compensate for modelling errors from the simplified FEM based WPM. Input variables for the neural network model are chosen by using the hypothesis testing. In addition, the width control scheme using the simplified FEM based WPM and the neural network based ECM is proposed to achieve the desired width margin in the finishing mill. It is shown through the field test of the Pohang no. 1 hot strip mill of POSCO that the performance with respect to the width margin is greatly improved by the proposed width control scheme based on two models.

(cf. *ISIJ Int.*, **47** (2007), 105)

Forming Processing and Thermomechanical Treatment

Surface oxidation of low carbon steel strip during batch annealing

P.R.WILSON et al.

Selective oxidation of low carbon strip steels industrially batch annealed in 4% hydrogen 96% nitrogen atmosphere was studied using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). It was found that the selective oxidation was not uniform across the width of the steel strip. The non-uniformity of the selective oxidation across the strip width produced the localised formation of (MnFe)O and $MnCr_2O_4$ particles along the ferrite grain boundaries, mainly in the vicinity of the strip edge region. The distribution of the $MnCr_2O_4$ particle sizes within this region can explain the generation of a defect on the final tinplate product, which manifests as a localised band of low reflectivity after tinplating of batch annealed strip, 'edge defect' that can be produced on batch annealed tinplate. The propensity for nitrogen absorption was also found to vary significantly across the strip width and was limited in the region where selective oxidation occurred. This non-uniformity in selective oxidation and nitrogen absorption is probably due to the changes in the dewpoint or oxygen potential of the annealing gas across the width of the strip.

(cf. *ISIJ Int.*, **47** (2007), 114)

Measurement of ductile forming limit in non-linear strain paths and anisotropic yield conditions for 11% Cr steel sheets

T.IGUCHI et al.

The ductile forming limit in nonlinear strain paths is investigated for a 11% Cr steel which displays a high r-value and is used practically in difficult forming applications. Experimental measurements were performed to examine the forming limit in strain paths which involve plane strain loading in first-stage loading and loading at various strain ratios in the second stage. Because the forming limit diagram (FLD) is not applicable to nonlinear loading paths, the forming limit stress diagram (FLSD) theory is investigated. In order to evaluate the stress at the forming limit from measured strain, the anisotropic yield criterion of the material is investigated by uniaxial tension testing in three directions and biaxial stretching using hydraulic bulging. Hill quadratic yield criterion gives the best approximation for biaxial tension, whereas Hosford criterion is more appropriate for uniaxial tension. Yld2000-2d is the ideal criterion for both stress states. Considering the possible effect of dependency of r-values on measured strain, the evolution of r-values is measured. Under sufficiently large strain, the r-value becomes virtually constant. Based on the preliminary investigation outlined above, it was found that the evaluated forming limit stresses in nonlinear strain paths lie on one consistent line in the principal stress field. The limit stress line is not affected by changes in the amount of strain applied in the first loading stage, demonstrating that the FLSD theory of ductile fracture is adequate for this particular material.

(cf. *ISIJ Int.*, **47** (2007), 122)

Numerical study of the collision dynamics and heat transfer of water droplets impinging on a hot solid

T.MINAMIKAWA et al.

The present study is concerned with the collision of two droplets with a hot solid substrate whose temperature is maintained below the boiling temperature of the liquid. Computer simulations were performed to investigate the heat transfer from the hot solid to the coaxially incoming droplets. The conservation equations of 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 viscosity, surface tension, gravity, and the heat transfer between the solid and the liquid. The effects of the impact conditions of the droplets, such as their impact velocity, their pre-impact diameters, and the vertical distance between two consecutive droplets on the heat transfer rate are examined. To validate the simulation results, experiments were performed in which the time evolution of the droplet shape was observed by photography. The numerical results are in reasonable agreement with the experimental data. We discuss the implications of these results for the theoretical understanding of the physics of heat transfer.

(cf. *ISIJ Int.*, **47** (2007), 131)

Welding and Joining

Pulsed current GMAW for superior weld quality of austenitic stainless steel sheet

P.K.GHOSH et al.

The performance of pulsed current gas metal arc welding (P-GMAW) and conventional gas metal arc welding (GMAW) processes in welding of 2.5 mm thin stainless steel sheet at different heat input has been studied. The use of P-GMAW at low heat input has been found superior to the use of GMAW process with respect to significant reduction in intergranular corrosion (IGC) susceptibility along with considerable improvement in some other characteristics of weld joint by maintaining comparable mechanical properties. It was further observed that the IGC, weld geometry and microstructure of P-GMA weld joint are largely governed by pulse parameters, and varies as a function of factor ϕ, defined as a summarized influence of pulse parameters such as peak current, base current, pulse-off time and pulse frequency. The increase of ϕ has been found favourable to reduce IGC, weld geometry along with refinement of the cast (dendritic) structure of weld deposit.

(cf. *ISIJ Int.*, **47** (2007), 138)

Surface Treatment and Corrosion

Corrosion inhibition by Cr-bearing rebar in concrete due to combined deterioration of carbonation and Chloride attack

S.-H.TAE et al.

With the aim of developing Cr-bearing rebars having required resistance to deteriorative environments prone to carbonation with or without chloride attack, ten types of steel bars having different Cr contents were embedded in concretes with chloride ion contents of 0, 0.3, 0.6, 1.2, and 2.4 kg/m^3 to fabricate specimens assuming such deteriorative environments. After being carbonated to the reinforcement level, these concretes were subjected to corrosion-accelerating cycles of heating/cooling and drying/wetting. The time-related changes in the corrosion area ratio and corrosion loss of the Cr-bearing rebars were then measured to investigate their corrosion resistance. The results revealed that the Cr content required for corrosion resistance in a simple carbonating environment was 5% or more. The corrosion-resisting performance of Cr-bearing rebar was particularly noticeable with a Cr content of 7% or more. In a deteriorative environment prone to both carbonation and chloride attack, corrosion resistance was evident with a Cr content of 7% or more and 9% or more in concretes with chloride ion contents of 1.2 and 2.4 kg/m^3, respectively.

(cf. *ISIJ Int.*, **47** (2007), 146)

Polypyrrole coating on zinc for corrosion prevention of zinc-coated steels

S.TSUCHIYA et al.

The polypyrrole (PPy) coating was prepared by constant current oxidation on zinc from aqueous solution of sodium tartrate containing sodium molybdate and pyrrole monomer to make new coating for corrosion prevention of zinc-coated steels.

The coating is started with an initial formation of salt layer of zinc tartrate and/nor zinc molybdate during the oxidation. Nucleation and growth of PPy take place on the salt layer in the second stage. The PPy layer thus formed is doped by tartrate ions

and/nor molybdate ions, which was confirmed by a depth profile measurement of glow discharge optical emission spectroscopy (GD-OES). The conductance of the coatings was as small as 1×10^{-3} S cm^{-2} for the 5 μm-thick layer probably due to the formation of the salt layer underneath the PPy layer. Corrosion test of the PPy-coated zinc electrode in 3.5 wt% NaCl solution showed that the zinc electrode was passivated and protected over 48 h by action of the oxidative PPy coating doped by tartrate and molybdate ions.

(cf. *ISIJ Int.*, **47** (2007), 151)

Transformations and Microstructures

Formation of surface nanocrystalline structure in steels by shot peening and role of strain gradient on grain refinement by deformation

Y.TODAKA et al.

The amount of strain provided by shot peening (SP) was estimated by comparing the shot-peened surface structure to the cold-rolled structure. The grain size of recrystallized structure beneath the shot-peened nanocrystalline (NC) surface after annealing was similar to that of the specimen after cold-rolling (equivalent strain $\varepsilon_{eq}=ca.$ 6) and annealing. The ε_{eq} larger than 6 seems to be given to the surface region by SP. This strain amount is consistent with the necessary condition ($\varepsilon_{eq}>7$) to produce NC structure proposed in the previous study. The large strain gradient is also generated at the shot-peened surface. The strain gradient has been suggested as one of important factors on strengthening and on grain refinement. The deformation by SP is complex; the role of strain gradient was investigated by using high-pressure torsion (HPT) process. The maximum hardness (Hv 5 GPa) in the Fe–0.03mass%C disk after HPT-straining was twice higher than the hardness (2.4 GPa) obtained by cold-rolling. At the center of HPT-processed disk, where shear strain is nominally zero, the hardness increased up to a saturation value of 3.3 GPa. These results in the HPT experiment show that strain gradient contributes to strengthening and to grain refinement. However, the grain refinement was saturated with around 200 nm in layered grain thickness although the HPT-processed disk was applied large strain and strain gradient. This suggests that not only strain gradient and strain but also other deformation conditions are necessary to form NC structure.

(cf. *ISIJ Int.*, **47** (2007), 157)

Thermodynamic calculations on the stability of Cu_2S in low carbon steels

B.-J.LEE et al.

Thermodynamic stability of Cu_2S sulfide in low carbon steels has been investigated using a CALPHAD type thermodynamic calculation method. Thermodynamic properties of the Cu–S binary and Fe–Cu–S ternary systems were critically assessed. By combining the newly assessed thermodynamic parameters to an existing thermodynamic database for steels, a thermodynamic description for low carbon steels involving sulfur and Cu could be obtained and be used to calculate phase equilibria and thermodynamic stability of precipitating phases such as AlN, MnS, and Cu_2S. It was predicted that the Cu_2S sulfide often observed in low carbon steels is actually a thermodynamically unstable phase and can precipitate when thermodynamic equilibrium state is not reached during steel making processes. Probable reasons and conditions for the formation of this unstable phase are discussed.

(cf. *ISIJ Int.*, **47** (2007), 163)

In situ synthesis of Ti_5Si_3 intermetallic particulate locally reinforced medium carbon steel-matrix composite *via* the SHS reaction of Fe–Ti–Si system during casting

S.L.LI et al.

The *in situ* Ti_5Si_3 intermetallic particulate locally reinforced steel matrix composites are successfully fabricated by the self-propagating high-temperature synthesis (SHS) reaction of Fe–Ti–Si system during casting, and the microstructures of the composites reveal a relatively uniform distribution of mango-like Ti_5Si_3 particulates in the local reinforcing regions. XRD results reveal that in addition to α-Fe and Ti_5Si_3 phases, the transient Fe_2Ti is also present in the local reinforcing region of the composites. Furthermore, some Ti_3SiC_2 particulates are formed and distribute in the limited region nearby the interface between the local reinforcing region and steel matrix. With Fe content increasing from 10 to 30 wt% in the preforms, the Ti_5Si_3 particulate size is decreased obviously in the local reinforcing region; furthermore, the presence of significant porosity can be detected in the composite synthesized by the 10 wt% Fe–Ti–Si system; on the contrary, only a minimal porosity can be found in that synthesized by 30 wt% Fe in Fe–Ti–Si system. The macro- and micro-hardness as well as the wear resistance of the local reinforcing region are obviously higher than those of the unreinforced medium steel. Improvements in hardness and wear resistance of the composite are mainly attributed to the presence of high volume fraction of hard intermetallic Ti_5Si_3 particulates.

(cf. *ISIJ Int.*, **47** (2007), 172)

Mechanical Properties

Quantitative evaluation of the impact fracture surfaces of SS400 steel by the three-dimensional geometrical analysis

M.TANAKA et al.

The fractal dimension and the surface roughness of the fracture surface was estimated using the height data generated by the stereo matching method on Charpy V-notch specimens of the SS400 steel impact-fractured in the temperature range from 194 K (−79°C) to 273 K (0°C). The representative fracture surfaces were quasi-cleavage fracture surface with river patterns and steps between facets at 194 K and ductile fracture surface with dimples and shear steps at 273 K. On the region close to the notch root (fracture initiation site), a definite correlation was not found between the absorbed energy and the fractal dimension of the fracture surface, but both absorbed energy and surface roughness increased with temperature because of increased proportion of ductile fracture surface with the larger surface roughness. There was essentially no difference in the fractal dimension between quasi-cleavage fracture surface and ductile fracture surface. Fracture process including fracture initiation, local crack growth or finally fractured part could be examined by the detection of characteristic fracture patterns using the fractal dimension map (FDM) and the surface roughness map (SRM). Detected steps of various sizes were associated with river patterns or fracture at ferrite grain boundaries on the quasi-cleavage fracture surface, and were associated with dimple walls or shear steps on the ductile fracture surface. Steps on both fracture surfaces were formed by common mechanism, namely, by plastic deformation (shear deformation). The density of steps was larger on the quasi-cleavage fracture surface than on the ductile fracture surface. These steps led to a large fractal dimension of the quasi-cleavage fracture surface comparable with the ductile fracture surface with dimples.

(cf. *ISIJ Int.*, **47** (2007), 178)