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Transformations and Microstructures

Decomposition of austenite in austenitic stainless steels (Review)

A.F.Padilha et al.

Austenitic stainless steels are probably the most important class of corrosion resistant metallic materials. In order to attain their good corrosion properties they rely essentially on two factors: a high chromium content that is responsible for the protective oxide film layer and a high nickel content that is responsible for the steel to remain austenitic. Thus the base composition is normally a Fe–Cr–Ni alloy. In practice the situation is much more complex with several other elements being present, such as, Mo, Mn, C, N among others. In such a complex situation one almost never has a single austenite phase but other phases invariably form. Those phases are, with few exceptions, undesirable and they can be detrimental to the corrosion and mechanical properties. It is therefore of considerable importance to study the formation of such phases. In this work the decomposition of austenite in austenitic stainless steels is reviewed in detail. First the binary equilibrium diagrams relevant to the system Fe–Cr–Ni are briefly presented as well as other diagrams, such as the Schaeffler diagram, that traditionally have been used to predict the phases present in these steels as a function of composition. Secondly the precipitation of carbides and intermetallic phases is presented in detail including nucleation sites and orientation relationships and the influence of several factors such as composition, previous deformation and solution annealing temperature. Next, the occurrence of other constituents such as nitrides, sulfides and borides is discussed. TTT diagrams are also briefly presented. Finally the formation of martensite in these steels is discussed.

(cf. *ISIJ Int.*, **42** (2002), 325)

Fundamentals of High Temperature Processes

Behavior of immiscible two liquid layers contained in cylindrical vessel suddenly set in rotation

T.Sugimoto et al.

Immiscible silicone oil and water were contained in a cylindrical vessel. The ratio of their volumes, referred to as the volume ratio, was varied over a wide range. The vessel was suddenly set in rotation, and the flow velocities of the two liquids were measured with particle image velocimetry (PIV) and laser Doppler velocimetry (LDV). The flow establishment time was defined as the period from the start of rotation to the moment at which a steady state is established in the vessel. An empirical equation for the flow establishment time was proposed as a function of the volume ratio, the angular frequency of rotation, and the physical properties of the liquids. The deformation of the silicone oil-water interface was also observed to confirm the findings obtained from the velocity measurements.

(cf. *ISIJ Int.*, **42** (2002), 338)

FT-IR spectroscopic study on structure of $CaO–SiO_2$ and $CaO–SiO_2–CaF_2$ Slags

J.H.Park et al.

The FT-IR spectra of the $CaO–SiO_2$ and $CaO–SiO_2–CaF_2$ slags were measured to understand the structural aspects of (fluoro-) silicate systems. The relative intensity of Si–O rocking band is very strong at SiO_2 saturation condition and this band disappears in the composition greater than 44.1 (mol%) CaO in the $CaO–SiO_2$ binary system. The bands for $[SiO_4]$-tetrahedra at about 1 150–760 cm^{-1} split up with increasing content of CaO greater than 44.1 mol%. The IR bands in this wavenumber range are divided into four groups, that is about 1090, 990, 920, and 870 cm^{-1}, which have been assigned to NBO/Si=1, 2, 3, and 4, respectively. In the $CaO–SiO_2–CaF_2$ ($2CaO \cdot SiO_2$-Satd.) system, the center of gravity of the bands at about 1 170–710 cm^{-1} shifts from about 980 to 850 cm^{-1} by increasing the ratio X_{CaF_2}/X_{SiO_2} from 0.22 to 0.64. The bands for $[SiO_4]$-tetrahedra are observed from about 1 070 to 730 cm^{-1} in the $CaO–17.6(mol\%)SiO_2–CaF_2$ system, while these bands are observed from about 1 120 to 720 cm^{-1} in the $CaO–40.0(mol\%)SiO_2–CaF_2$ system. The effect of substitution of CaF_2 for CaO on the depolymerization of silicate network is observed to significantly depend on the SiO_2 content in the slags. The bands for $[SiO_4]$-tetrahedra are observed from about 1 110 to 720 cm^{-1} in the $CaO–SiO_2–14.1(mol\%)CaF_2$ system and the center of gravity of these bands shifts from about 990 to 850 cm^{-1} with increasing CaO/SiO_2 ratio. The fraction of the relatively depolymerized units continuously increases from about 0.5 to 0.8 as the composition of slags changes from $2CaO \cdot SiO_2$ to CaO saturation condition.

(cf. *ISIJ Int.*, **42** (2002), 344)

Steelmaking

Effect of fluorine on silicate network for $CaO–CaF_2–SiO_2$ and $CaO–CaF_2–SiO_2–FeO_x$ glasses

M.Hayashi et al.

The chemical state of fluorine and the effect of fluorine addition on the degree of polymerization of silicate network have been investigated for the $CaO–SiO_2–CaF_2$ and $CaO–SiO_2–CaF_2–FeO_x$ glasses using the X-ray photoelectron spectroscopy (XPS) and Mössbauer spectroscopy measurements. The F1s XPS spectra indicate that the fluorine is dominantly coordinated with calcium rather than silicon. The O1s XPS spectra for the $CaO–SiO_2–CaF_2$ glasses and the values of Fe^{2+}/Fe^{3+} obtained by Mössbauer spectra for the $CaO–SiO_2–CaF_2–FeO_x$ glasses indicate that CaF_2 addition does not depolymerize the silicate network for both systems.

(cf. *ISIJ Int.*, **42** (2002), 353)

Casting and Solidification

Modeling of dendritic growth with convection using a modified cellular automaton model with a diffuse interface

Y.H.Shin et al.

A modified cellular automaton model with a diffuse interface has been developed in order to investigate the effects of convection on dendritic growth morphology in an undercooled melt. The present model is based on the coupling of the dendritic growth algorithm generally used in cellular automaton models and the continuum model of phase field models. A diffuse interface is adopted in order to solve the continuum model for species and momentum transfer with convection. The asymmetrical growth of dendrite arms and the deflection behavior have been investigated with various parameters, such as the preferred orientation of crystal growth, the inlet flow velocity, the initial liquid concentration, and the initial supercooling of the melt. It was found that convection induces an asymmetric dendritic growth in the upstream direction, caused by the asymmetry of solute distribution in the liquid ahead of the solid/liquid interface. The asymmetry in dendritic growth is amplified with the increase of both the initial concentration and the flow velocity, and the asymmetry decreases with the increase of the initial supercooling. It can be concluded that the present model can be successfully applied to simulate dendritic growth morphology with convection.

(cf. *ISIJ Int.*, **42** (2002), 359)

Numerical simulation of initial microstructure evolution of Fe–C alloys using a phase-field model

M.Ode et al.

Microstructure evolution during the rapid solidification of Fe–C and Fe–C–P alloys is simulated using the phase-field model for alloys with thin interface limit parameters. Heat transfer equation is solved simultaneously to study the heat flow and the effect of latent heat generation on the microstructure. The calculations have been carried out using a double grid method and parallel computing technique. The competitive growth of growing cells is reproduced, and the cellular/dendritic transition is also observed. Since there is a negative thermal gradient in front of a leading tip, the growth can be regarded as unidirectional free dendrite growth. The microstructure changes depending on the preferred growth orientation and impurity are also studied. The secondary arms grow preferably towards inside of the melt and develop well with increase of the tilted angle. The secondary and primary arm spacing decrease by the small amount of phosphorus addition. The time change of averaged surface temperature depending on the initial undercooling shows that the surface undercooling is always observed even when the initial value is zero.

(cf. *ISIJ Int.*, **42** (2002), 368)

Prediction of density of carbon steels

H.Mizukami et al.

The change in the density of carbon steel with phase at a temperature range from 1 000 to 1 973 K has been studied by a sessile drop profile method. Measurement of the density by a sessile drop profile method has to be carried out under heating conditions to avoid the influence of both undercooling and the shrinkage within the sample during solidification. The density of carbon steel was dependent on the phase but not carbon, silicon, manganese,

phosphorus and sulfur contents.

The density in L, δ and γ single phase regions, (L+δ), (L+γ), (δ+γ) two phases regions and (L+δ+γ) three phase region could be predicted using the experimental results for Fe–C binary steel and steel contained alloying elements.

These estimated values are in good agreement with experimental results.

(cf. *ISIJ Int.*, **42** (2002), 375)

Laboratory scale continuous casting of steel billet with high frequency magnetic field

J.PARK et al.

The objective of this study is to improve the surface quality of the billet by applying high-frequency magnetic field electromagnetic casting technology to the continuous casting of steel. In this study, the effect of the mold shape on the steel billet surface quality was examined by a continuous casting experiment. It also researched the effects of electromagnetic field on the surface quality of the billet by observing the shape of the early-solidified shell as well as measuring the meniscus shape and mold flux consumption.

Through the experiment, it was found that billet surface roughness was improved to 1/5 of the conventionally cast billets under an optimum condition. This study also discovered that a hook formed on the early-solidified shell and molten steel overflowed when an electromagnetic field was not applied. However, in the electromagnetic casting, a hook did not form in the meniscus and the early-solidified shell grew and became thin and even. The corner shape of the mold also had a great effect on the surface quality of billet's corner. In addition, it was found that mold flux consumption is increased during electromagnetic casting.

(cf. *ISIJ Int.*, **42** (2002), 385)

Forming Processing and Thermomechanical Treatment

A finite element model for the prediction of thermal and metallurgical behavior of strip on run-out-table in hot rolling

C.G.SUN et al.

A finite element-based, integrated process model is presented for a three dimensional, coupled analysis of the thermal and metallurgical behavior of the strip occurring on the run-out-table in hot strip rolling. The validity of the proposed model is examined through comparison with thermal measurements. The model's capability of revealing the effect of diverse process parameters is demonstrated through a series of process simulation.

(cf. *ISIJ Int.*, **42** (2002), 392)

Welding and Joining

Metallurgical and mechanical properties of high nitrogen austenitic stainless steel friction welds

I.WOO et al.

Friction welding of high nitrogen austenitic stainless steels was carried out using a pressure servo-control system brake type device. The welding parameters were 2 400 rpm for rotational rate, 70 MPa for 4, 7, 10 and 15 s for friction pressure, and 150 MPa for 6 s for upset pressure. As the friction time increased, the fully plastically deformed zone (Region I) in the vicinity of the bond-line increased. In contrast, an increase in friction time decreased the region (Region II) where the grains were partly deformed and grown. The TEM examination suggested that the intergranular phases precipitated in the vicinity of the bond-line are Cr_2N (Hexagonal, a=0.48113 nm, c=0.44841 nm) and CrN (Cubic, a=0.4140 nm). Tensile test results indicated that high nitrogen stainless steel joints are considerably higher in the tensile strength than the commercial stainless steel SUS316L or SUS304 joints. However, for all the welding conditions, the joint strength of high nitrogen HNS-1 or HNS-2 joints was slightly lower than that of the base material. Furthermore, the detailed fractographic observation confirmed that the rupture occurred near the bonding interface. The inferior tensile strength of the nitrogen-containing austenitic stainless steel joint could be attributed to the Cr–nitrides precipitated near the bonding interface.

(cf. *ISIJ Int.*, **42** (2002), 401)

Sueface Treatment and Corrosion

Flow field analysis inside a molten Zn pot of the continuous hot-dip galvanizing process

S.J.LEE et al.

The flow field inside a molten zinc pot of the continuous hot-dip galvanizing process of steel strips was investigated experimentally. A 1/5-scale transparent water model with induction heaters, scrapers, and baffles was used in this study. Instantaneous velocity fields were measured using a single-frame PIV velocity field measurement technique with varying the strip velocity V_S, flow rate Q of the induction heater, scraper location, and baffle type. The general flow pattern inside the strip region is hardly influenced by the strip speed V_S, flow rate Q, and the scraper location around the stabilizing roll. When the induction heater is not operated, a pair of vortices is formed in the inner part of the strip: a clockwise rotating flow at the entrance region and a counter-clockwise rotating flow at the exit region.

In the exit region outside of the strip, the flow detached from the stabilizing roll divides into two parts: a counter-clockwise rotating flow in the upper region and a clockwise rotating flow in the lower region. For the cases of no scrapper and scrapper, detached from the stabilizing roll, the flow separates from the moving strip and ascends to the free surface. As the flow rate of the induction heater increases, the ascending flow is weakened and the counter-clockwise rotating flow in the upper area of the outside region becomes tranquil. This indicates that the flow in the upper area of the exit region is greatly influenced by the operation of the induction heater. When a scraper is attached onto the stabilizing roll, the separated flow from the strip is guided downward and the up-rising flow around the stabilizing roll becomes slow and tranquil. By attaching baffles near the moving strip in addition to the stabilizing rolls, the flow entrainment into the corner region between the strip and the stabilizing roll is greatly reduced. These flow control devices should be helpful in reducing top drosses in the zinc plating process.

(cf. *ISIJ Int.*, **42** (2002), 407)

Transformations and Microstructures

A metallographic analysis of intercritically deformed C-Mn steel subjected to complex strain histories

D.N.HANLON et al.

The microstructure of intercritically deformed lean steels is known to be rather complex, showing significant variations as a function of the imposed strain path. This paper describes a detailed metallographic study of an intercritically deformed C–Mn steel and a generally applicable methodology for determining the relevant metallographic processes from specific combinations of metallurgical features.

(cf. *ISIJ Int.*, **42** (2002), 414)

Static recrystallization and induced precipitation in a low Nb microalloyed steel

M.GÓMEZ et al.

By simulation of hot rolling using torsion tests and subsequent graphic representation of mean flow stress (MFS) *versus* the inverse of temperature for each pass, no-recrystallization temperature (T_{nr}) was determined for a low niobium microalloyed steel at different interpass times and two strains of 0.20 and 0.35. Recrystallized fraction (X_a) against time curves and RPTT diagrams were also determined for these two strains. This work has allowed evaluation of the influence of a very low Nb content on three aspects: T_{nr}, the residual stress accumulated in the austenite just before the $\gamma \rightarrow \alpha$ transformation ($\Delta\sigma_r$), and recrystallization–precipitation interaction. It was found that when the strain applied was 0.2 and the interpass times were less than 30 s, the values of T_{nr} and $\Delta\sigma_r$ were rather high. However, greater strains and interpass times brought about very small values of T_{nr} and $\Delta\sigma_r$. In addition to this, new aspects about the definition of T_{nr} are also discussed in this paper.

(cf. *ISIJ Int.*, **42** (2002), 423)

Dynamic restoration process of Ni–30Fe alloy during hot deformation

D.-W.SUH et al.

Change in deformed microstructure with dynamic restoration at various strain, strain rate and deformation temperature was examined for a Ni–30Fe alloy during hot deformation. A screw embedded specimen is used for quantitative evaluation of the distribution of compressive strain in the hot compressed specimen. A typical microstructural evolution due to dynamic recrystallization is observed at a deformation temperature of 1 173 K at a strain rate of 10/s and at 1 073 K and 1 173 K at a strain rate of 0.1/s. On the other hand, when the compressive strain exceeds 3.2, a characteristic microstructure consisting

of equiaxed recovered grains is developed at a deformation temperature of 973 K at a strain rate of 0.1/s and at deformation temperatures of 973 K and 1 073 K at a strain rate of 10/s. The interpenetration of the serrated austenite grain boundaries, so-called geometric recrystallization, is thought to be responsible for microstructural evolution of the equiaxed recovered grains.

(cf. *ISIJ Int.*, **42** (2002), 432)

The relationship between primary and secondary recrystallization texture of grain oriented silicon steel

T.KUMANO et al.

The relationship between primary and secondary recrystallization texture of grain oriented silicon steel, of which process is the only one case applying the secondary recrystallization phenomenon in the steel industry, was examined. The specimens with various kinds of the primary texture were obtained by changing the cold rolling reduction and carbon content, and were secondary-recrystallized by injected inhibitor method. It was reconfirmed that in order to realize the sharp Goss orientation ($\{110\}\langle001\rangle$), the intensity of $\Sigma9$ coincidence boundaries for Goss orientation will be strong and $\Sigma9$ coincidence boundaries will move faster than $\Sigma5$ boundaries.

(cf. *ISIJ Int.*, **42** (2002), 440)

Mechanical Properties

Retained austenite characteristics and stretch-flangeability of high-strength low-alloy TRIP type bainitic sheet steels

K.SUGIMOTO et al.

Retained austenite characteristics and stretch-flangeability in low alloy TRIP type bainitic sheet steels with different silicon and manganese contents were investigated for automotive applications. As increasing silicon and manganese contents, an initial volume fraction of retained austenite film along bainitic ferrite lath boundary was increased in accompany with a decrease in the carbon concentration. An excellent stretch-flangeability was completed in the steels containing a small amount of stable retained austenites (*i.e.*, volume fraction of 2–4 vol% and carbon concentration of more than 1.0 mass%). This was caused by small surface damage on hole-punching and effective strain-induced transformation plasticity of untransformed retained austenite on hole-expanding. When austempered at temperatures less than M_S of the steel after intercritical annealing, further superior stretch-flangeability was achieved due to absence of initial blocky martensite, resulting from developments of long shear section and severe plastic flow and difficult void-initiation on hole-punching.

(cf. *ISIJ Int.*, **42** (2002), 450)