

Forming Processing and Thermomechanical Treatment

The hot strip mill as an experimental tool (Review)

J.J.JONAS

The occurrence of carbonitride precipitation during the short interpass times associated with hot strip rolling is considered, together with the interaction between precipitation and static recrystallization under these conditions. The characteristics of work hardening and of strain accumulation at the high temperatures (850 to 1050°C) involved in strip rolling are described. Expressions are introduced that specify the kinetics of softening (by static or metadynamic recrystallization) during the interpass interval in various grades of steel. Using these kinetics in an appropriate mill model, the mean flow stresses pertaining to various mill stands are predicted. These values are compared with the measured ones derived directly from mill logs. It is shown how discrepancies between the predicted and measured values can be used to improve the accuracy of the expressions for the kinetics. This is one way in which a hot strip mill can be used as an "experimental tool".

(cf. *ISIJ Int.*, **40** (2000), 731)

Fundamentals of High Temperature Processes

Infrared emission spectra of CaF₂-CaO-SiO₂ melt

S.UEDA *et al.*

The infrared emission spectra of CaF₂-CaO-SiO₂ melt were investigated by a method combining infrared emission spectroscopy and the hot-filament technique. Emission for spectra related to Si-O bond can be observed by this *in situ* technique. The influence of SiO₂ and fluoride content on the spectrum was investigated, and the emission attributable to bonds corresponding to silicon-bridging oxygen and silicon-non bridging oxygen was discussed. Results suggest that fluoride ion dominantly substitutes for a non-bridging bond in low SiO₂ concentration region. The structure of silicate was compared with calculated infrared emission of Si-F-O.

(cf. *ISIJ Int.*, **40** (2000), 739)

Ironmaking

Reaction behavior of coke lump in raceway of blast furnace with pulverized coal injection

I.NARUSE *et al.*

Reaction behaviors of a coke lump in raceway of blast furnaces which pulverized coal injection technology was adopted were studied by using a horizontal pulverized coal reactor. In the experiments two types of coke lump were used as samples. In the experiments, the reaction behaviors of coke lump were continuously observed by an 8 mm video camera system. Mass change of the coke lump was weighed at each exposure time, and surface temperature of the coke lump was also continuously measured by a two-color pyrometer. Additionally, both the reacting coal particles and gas were sampled and analyzed, and the deposition on the coke surface

was also analyzed. In order to elucidate the effect of ash particles in coal on the coke reaction, LPG was also supplied as a fuel into the reactor instead of coal.

As a result, mass loss of coke in the coal combustion is larger than that in the LPG combustion. When the coal particles collide with the coke at the surface, the ash particles easily stick there and spherical molten ash is formed on the surface. For the LPG combustion, only small spherical molten ash resulted from the coke is formed. Those results suggest that ash particles of the coal may enhance coke degradation due to chemical interactions between coal ash and coke.

(cf. *ISIJ Int.*, **40** (2000), 744)

Steelmaking

Numerical calculation of circulation flow rate in the degassing Rheinstahl-Heraeus process

Y.-G.PARK *et al.*

The circulation flow rate of a steel melt, which is one of the important factors which determine decarburization rate of RH system, was calculated by using a 3-dimensional numerical simulation technique. A new model for evaluating the shape and volume of the plume zone, formed by Ar gas blown through multiple nozzles on the wall of the snorkel, was proposed to determine the driving force of melt circulation.

Circulation flow rates were measured in the 1/10 scale water model and in a real RH system to verify the calculation results with good agreement with the calculated circulation flow rates.

Because the computer program can calculate the circulation flow rates at various operating conditions and dimensions of the RH system, it may be useful in determining the optimum operating conditions and designing new RH systems.

(cf. *ISIJ Int.*, **40** (2000), 749)

Casting and Solidification

Further results from strip casting with the single-belt process

K.SCHWERDTFEGER *et al.*

The integrated single-belt casting/hot rolling process operated at Clausthal Technical University is described with emphasis on the machine operation. Automatic control of the relevant parameters is very important in strip casting with high linear velocities involving the additional process steps of hot rolling and coiling. The following quantities are measured, controlled and/or stored as process data by a computer system: (a) the temperatures of the liquid steel in the furnace/ladle and in the dispenser and of the strand at the entrance to the rolls, (b) the flow rate of the liquid steel discharged from the ladle into the dispenser, (c) the velocities of the belt, of the strand and of the rolled strip, (d) the roll gap, (e) the lateral position of the belt, and (f) the oxygen content of the gas in the strand encasing. The various controls are described and examples of the time records of the controlled quantities are given. The second part of the paper deals with the feeding sys-

tem. At present two argon rakes made up from a row of little argon jets are used to enhance the lateral distribution of the melt on the belt. In the third part of the paper the materials properties of the product are discussed. It is shown that the internal porosity can be removed securely by hot rolling with a reduction degree of about one. Some results are given on the inclusion distribution in the as-cast material.

(cf. *ISIJ Int.*, **40** (2000), 756)

The mechanism of unsteady bulging and its analysis with the finite element method for continuously casted steel

J.D.LEE *et al.*

The movements of the driven rolls were measured during the continuous casting of steel and their fluctuations were compared with other signals such as the casting speed and the mold level. From the observation of large fluctuations in the movements of the driven rolls and the unevenness in the thickness of the solid shell, it is proposed that the unevenness in the thickness of the solid shell is the main reason for unsteady bulging during the casting of medium carbon steel. A two-dimensional model over the successive rolls was used to calculate the bulging profile and its changes with time, during the fluctuations in the casting speed, with the finite element method. As a result, the calculations were in good agreement with the experimental results, and, it could be concluded that the period of unsteady bulging is greatly influenced by the roll pitch, therefore, depends on the locations where different roll pitches occur, and is somewhat affected by casting speed variations. Finally, based on the calculations and the experimental results, the effect of the unsteady bulging on the mold level was discussed.

(cf. *ISIJ Int.*, **40** (2000), 765)

Instrumentation, Control and System Engineering

A new mill-setup system for hot strip finishing mill integrating a process model and expertise

T.WATANABE *et al.*

This paper describes a new mill-setup system for a hot strip finishing mill in the iron and steel making industry, that integrates process models and operator expertise. Operator expertise is expressed in terms of roll gap differences between neighboring stands to avoid excessive loads that may lead to unstable rolling. The problem is formulated as that of minimizing deviation between the know-how-based roll gap difference pattern and the actual one. In order to realize such mill set-up considering the roll gap differences in actual plant, in which the computational time is strictly restricted, an estimation method of the Jacobian matrix for solving the problem is proposed. The efficiency and validity of the method are discussed, based on the linear system theory and case study results of simulations. The method is found to have valid computational properties for applying to the actual set-up of the process. Applying the system to the actual plant, it was found that operator intervention has been markedly reduced compared with the conventional set-up method. Further-

more the stability of operation, *i.e.* a decrease in the frequency of defective rolls, is also achieved.

(*cf. ISIJ Int.*, **40** (2000), 772)

Chemical and Physical Analysis

Determination of trace impurities in graphite and silicon carbide by total reflection X-ray fluorescence spectrometry after homogeneous liquid-liquid extraction

H. YAMAGUCHI et al.

Using homogeneous liquid-liquid extraction as a pre-concentration method, a determination procedure of trace impurities (Fe, Ni and Cu) by total reflection X-ray fluorescence (TXRF) analysis was developed and optimized for graphite and silicon carbide samples. The samples were decomposed by alkali fusion. The residue was dissolved in a mixture of pentadeca-fluorooctanoic acid (PFOA), acetone and water, and the analytes were homogeneously dispersed by the aid of phenanthroline (phen). After phase separation with pH-adjustment, a portion of the sedimented water-immiscible liquid was pipetted on the polyester film that covered a silicon wafer sample-carrier. Then, the droplet was dried in a vacuum and analyzed by TXRF. Analytical values in the sub-ppm or ppm level were well agreed with the certified values of the standard samples or the values observed by ICP-OES for a few samples.

(*cf. ISIJ Int.*, **40** (2000), 780)

Application of dc voltage modulation technique to the determination of phosphorous and sulfur in steel samples in glow discharge optical emission spectrometry

K. WAGATSUMA

An applied voltage modulation technique was applied to the high-sensitivity determination of phosphorous and sulfur in steel samples in glow discharge optical emission spectrometry. Emission signals from the glow discharge plasma were modulated by a cyclic variation of the discharge voltage so that only the desired signals could be detected without any noises with a DSP lock-in amplifier. The relative lock-in signals from sputtered species were enhanced compared to those of gas species. The PI 177.49-nm, and the SI 180.73-nm and SI 182.72-nm lines, were selected as the analytical lines. The limit of determination for the PI 177.49-nm line was estimated to be 1.0×10^{-3} mass% P.

(*cf. ISIJ Int.*, **40** (2000), 784)

Forming Processing and Thermomechanical Treatment

Nucleation and growth process of sticking particles in ferritic stainless steel

W. JIN et al.

Nucleation and growth process of sticking particle in ferritic stainless steels was investigated using

a two-disk type hot rolling simulator. The sticking behavior was strongly dependent on the surface roughness of a high speed steel roll (HSS) and the oxidation resistance of the ferritic stainless steels. A sticking occurrence was more sensitive for the steels containing higher chromium. There was a critical value which was found to be $3 \mu\text{m}$ of scale thickness in the suppression of the sticking phenomenon. It was also illustrated that the initial sticking particles were nucleated at the scratches formed on the roll surface and were served as the sticking growth sites. As rolling proceeded, the sticking particles grew by the process that the previous sticking particles provided the sticking growth sites.

(*cf. ISIJ Int.*, **40** (2000), 790)

Prediction of roll thermal profile in hot strip rolling by the finite element method

C. G. SUN et al.

An, FE-based, off-line model is presented for the precise prediction of roll thermal profile. The validity of the model is demonstrated through comparison with measurements. Also demonstrated is its capability of reflecting the effect of diverse process variables.

(*cf. ISIJ Int.*, **40** (2000), 795)

Transformations and Microstructures

Decomposition processes of δ -ferrite during continuous heating in a 25Cr-7Ni-0.14N stainless steel

S. KOBAYASHI et al.

Decomposition processes of the body-centered cubic (bcc) δ -ferrite phase in a 25Cr-7Ni-0.14N stainless steel have been investigated at temperatures below 600°C by means of differential scanning calorimetry (DSC), electric resistivity measurement (ERM) and transmission electron microscopy (TEM). Specimens were solution-treated at 1400°C for 15 min to produce δ single-phase structure and then quenched into iced water. The quenched specimens were continuously heated at various constant rates. During the heating up to 600°C , the reactions occurred in the following sequence: concentration fluctuation of nitrogen (N); chromium (Cr) modulated structure; homogeneous precipitation of fine Cr_2N platelets; growth of the Cr_2N platelets with eliminating the concentration fluctuations; and precipitation of spherical Cu particles. The orientation relationship between the Cr_2N and the δ phase matrix can be expressed as $[101]_{\delta} // [1210]_{\text{Cr}_2\text{N}}$ and $(\bar{1}01)_{\delta} // (0001)_{\text{Cr}_2\text{N}}$, the habit plane being $(\bar{1}00)_{\delta} // (\bar{1}2\bar{1}2)_{\text{Cr}_2\text{N}}$. The interface between the Cr_2N and the δ phase was coherent, though slight lattice displacements existed. The spherical particles are probably bcc copper (Cu).

(*cf. ISIJ Int.*, **40** (2000), 803)

Nano-investigation on grain boundary periodic alternating segregation based on divorced coincident segregation mechanism, resulted in the replacement of conventional site competition in steels

H. MABUCHI et al.

The segregation mechanism of alloying elements in prior austenitic grain boundaries of embrittled 5% Ni steels has been investigated by AES in previous studies, while that of improved 5% Ni steels has not been clarified yet. In the present study, the segregating behavior of alloying elements in improved 5% Ni steels has been elucidated for the first time by applying FE-TEM with respect to the effects of soluble Al on the suppression of temper embrittlement and hydrogen embrittlement in the steels.

It is consequently made clear by applying FE-TEM-EDS that alloying elements tend to segregate coincidentally to grain boundaries, showing the asymmetric segregation according to solute interactions. The observed behavior is newly defined as the divorced coincident segregation, which is considered to result from the moderate site competitions in the deep potential well of McLean's equilibrium segregation. The divorced coincident segregation was investigated further along grain boundaries, where the periodic segregation of Al and Si was found to vary alternately along grain boundaries analyzed.

The beneficial effect of soluble Al on the two types embrittlement is attributed to the mechanism of spot toughening through the periodic decrease of solutes in grain boundaries. The principle of the divorced coincident segregation proposed in 5% Ni steels can be applicable not only to ordinary steels but also to other poly-crystalline alloys in improving their properties.

(*cf. ISIJ Int.*, **40** (2000), 810)

Hot deformation and acicular ferrite microstructure in C-Mn steel containing Ti_2O_3 inclusions

J.-H. SHIM et al.

The influence of hot deformation on the formation of acicular ferrite in C-Mn wrought steels containing Ti_2O_3 inclusions has been investigated. A significant amount of acicular ferrite is formed even after hot deformation. From this, it seems that the ability of Ti_2O_3 inclusions to induce the nucleation of intragranular ferrite remains valid within recrystallized austenite grains after deformation. However, the fractions of acicular ferrite are lower than those in the steels without hot deformation. A high fraction of acicular ferrite is obtained after hot deformation when Mn level is high, the formation of intergranular ferrite such as allotriomorphic ferrite and upper bainite being pronouncedly suppressed. Deformation at relatively low temperatures discourages the formation of acicular ferrite while encouraging intergranular ferrite by reducing prior austenite grain size and consequently by increasing the area of the austenite grain boundaries.

(*cf. ISIJ Int.*, **40** (2000), 820)