Fundamentals of High Temperature Processes

A numerical analysis of single char particle heated by a laser

M.Ishigaki et al.

An unsteady state boundary layer model was developed in order to analyse the combustion of single char particles in radiation fields. The model is based on the following assumptions, a spherical char particle with small diameter is combusted at atmospheric pressure, the temperature difference between the surface and the inside of the particle is negligible, particle diameter shrinks due to the reaction on the char surface, the surrounding gas is stagnant, but Stefan flow is taken into consideration and bulk gas flow is neglected. The model predicts the particle temperature increase and the distributions of gas temperature and gas components in the boundary layer. The computed distribution of gas component proves clearly that the reaction rate is mainly controlled by oxygen diffusion in the boundary layer except during the initial heating and reaction. Using the simulation model, the effects of particle size, oxygen content in bulk gas and input laser power is discussed. The results predict that smaller particles heat up faster in initial heating and higher laser input has the same effect. Further, it is shown that a higher oxygen content raises the sustained combustion temperature and shortens the combustion period.

Infiltration of microporous activated charcoal by pyrolysis of CH_4 and its effect on enhancement of resistance against oxidation

Y.Shigeno et al.

Pores within activated charcoal (A.C.) were infiltrated by pyrolitic carbon derived from thermal decomposition of CH_4. The infiltrated activated charcoal showed an increase in resistance against oxidation with CO_2. To elucidate the mechanism of this effect, the pore size distribution of macropores, mesopores and micropores including submicropores were characterized for the original A.C., infiltrated A.C., oxidized A.C. and A.C. oxidized after infiltration, respectively. It was found that the infiltration decreased the volume and the surface area of pores, particularly the surface area of micropores.

When oxidized, the carbon which deposited in macropores is almost burned but that in meso-and micropores is only partly burned; The ratio of increase in surface area of the infiltrated sample is smallest for the micropores. From these experimental results, it is deducible that the deposited carbon in micropores plays the major role for blocking CO_2 intruding, thereby the resistance against oxidation is enhanced.

Ironmaking and Reduction

A mathematical model for blast furnace reaction analysis based on the four fluid model

P.R.Austin et al.

A two dimensional mathematical model is developed describing four phase chemical reactions, motion, and heat transfer in the blast furnace. The four phases are gas, lump solid, liquid and powder. The model simultaneously calculates the steady state composition, velocity, temperature, and volume fraction of all four phases. The predicted gas, solid and liquid phase compositions are plausible, but the fines dynamic holdup distribution is sensitive to the fines consumption processes in the raceway. The model has also been extended to include silicon transfer reactions. Compared to the base calculations, the predicted cohesive zone position is higher and the bosh is cooler when silicon transfer is included. The model predicts SiO generation from both coke ash silica and molten silica, the latter being the main contributor to hot metal silicon content in the case considered.

Some kinetic aspects of reduction of FeO in molten slags by solute carbon

R.K.Paramguru et al.

This paper reports some experimental observations on reduction of FeO in molten slags by carbon saturated iron bath. A. Tammann furnace was used to study the reaction. Kinetic results indicate a first order reaction with respect to FeO concentration. Results also indicate that the gas generated during the reduction reaction plays a significant role through stirring of the bath. A correlation established through the Morton number and the Reynolds number provides further insight into this phenomenon. Degree of reaction, defined using optical basicity values calculated on the basis of the overall composition of the slag provides results comparable to those obtained from the conventional values calculated on the basis of FeO concentration.

Steelmaking and Refining

Electrochemical measurement of critical supersaturation in Fe-O-M (M=Al, Si, and Zr) and Fe-O-Al-M (M=C, Mn, Cr, Si, and Ti) melts by solid electrolyte galvanic cell

G.Li et al.

The supersaturation ratio with respect to alumina precipitation, $S^{\circ}_{Al_2O_3}(=(a^2_{\underline{Al}}\cdot a^3_{\underline{O}})_{ss}/(a^2_{\underline{Al}}\cdot a^3_{\underline{O}})_{eq})$, in Fe-O-0.088~0.090mass%Al melt was electrochemically measured at 1 873 K in an Al_2O_3 crucible by blowing CO_2 gas or adding an Fe-2mass%Al alloy intermittently, using plug-type ZrO_2-9mol%MgO and tube-type mullite probes. The $S^{\circ}_{ZrO_2}(=(a_{\underline{Zr}}\cdot a^2_{\underline{O}})_{ss}/(a_{\underline{Zr}}\cdot a^2_{\underline{O}})_{eq})$ value in Fe-0.04mass%Zr-O melt was also measured at 1 873 K in a ZrO_2-11mol%CaO crucible by adding an Fe-4mass% Zr alloy. As a result, the critical values for log $S^{\circ}_{Al_2O_3}$ and log $S^{\circ}_{ZrO_2}$ were 3.5 and 1.3, respectively. No supersaturation for the precipitation of SiO_2 was observed. The presence of solute element M (M=C, Mn, Cr, Si, and Ti) in an Fe-O-0.148~0.158mass%Al melt was found to significantly influence the supersaturation phenomenon.

Casting and Solidification

Effect of crucible materials and oxides on static undercooling in molten nickel

A.Abedi et al.

Using fused silica and alumina crucibles, an investigation on the static undercooling behavior of nickel, with and without the addition of oxides, was conducted. The effects of the crucible materials and of the oxides on the undercooling and solidified structure were investigated.

The degree of undercooling reached 192 K using the fused silica crucible, and decreased to an average of 55 K using the alumina crucible. With the addition of alumina powder to the nickel, the lowest undercoolings were obtained. Considering a modified planar disregistry between nickel and alumina might explain why alumina acts as a good heterogeneous nucleation catalyst in molten nickel.

The addition of the alumina powder did not significantly refine the solidified structure of the specimens. The finest structures were obtained in the specimens with added NiO and Co_3O_4 powders which had almost no effect on the undercooling.

Surface Science and Technology

Characterization of the Fe-Al interfacial layer in a commercial hot-dip galvanized coating

E.McDevitt et al.

Recently there has been substantial interest in the formation of transient Fe-Al interfacial layers during hot-dip galvanizing and galvannealing. These layers delay the formation of Fe-Zn intermetallic compounds by preventing the interdiffusion of Zn and Fe. Despite the industrial importance of this inhibition phenomenon and the resulting research on the subject, there remains considerable uncertainty about the nature of the Fe-Al inhibition layer. In this study, the inhibition layer on commercially produced hot-dip galvanized steel is characterized using a combination of conventional and analytical SEM and TEM and X-ray diffraction. A reproducible technique for extracting the interfacial layer for the purpose of making plane-view TEM specimens is presented. Using this combined TEM, SEM X-ray diffraction method, it is shown

that the inhibition layer is composed of a layered structure of Fe_2Al_5 and $FeAl_3$. It is also demonstrated that X-ray diffraction alone may fail to detect the $FeAl_3$ phase and that a combined method using both TEM and X-ray diffraction is best suited for characterizing these interfacial layers. Additionally, it is shown that grain boundary diffusion of Zn within the Fe-Al interfacial layer may play an important role in the eventual transformation of the inhibition layer.

Microstructure

Recrystallization-induced precipitation interaction in a medium carbon vanadium microalloyed steel

A. QUISPE et al.

Using torsion tests, a study has been made of recrystallization-precipitation (R-P) interaction in a vanadium microalloyed steel for two strains (0.20 and 0.35). When strain induced precipitations starts, the recrystallized fraction deviates from Avrami's equation, giving rise to the formation of a plateau on the curves which represent the recrystallized fraction against time. This makes it possible to know the moment at which precipitation starts (P_s) and the moment at which it finishes (P_f). After the end of precipitation, recrystallization continues to progress in accordance with Avrami' s law. Recrystallization-Precipitation-Time-Temperature (RPTT) diagrams have been drawn, superposing on them the lines corresponding to different recrystallized fractions. This makes it possible to represent in graph form the Recrystallization-Precipitation interaction and the determination of the static recrystallization critical temperature (SRCT). It is demonstrated that during the interval of time in which precipitation occurs (P_f-P_s), recrystallization dose not advance. The work which has been carried out establishes new aspects in the phenomenon of R-P interaction.

Bainite transformation in a silicon steel

Y.C. JUNG et al.

The processes of upper bainite formation, the crystallographic aspects and the internal structure in a 1.83% silicon steel have been investigated. The T-T-T diagram is separated into two C-curves as in the case of steels containing strong carbide forming elements. In the early stage of upper bainitic transformation, very fine needlelike ferrite subunits with the parallelogram cross sections elongated in a $\langle 110\rangle_\gamma \parallel \langle 111\rangle_\alpha$ direction form on a $\{111\}_\gamma$ sheet in a side-by-side fashion. In the later stage of transformation, these subunits are coalesced on a $\{111\}_\gamma$ plane and produces upper bainite laths. This bainite is always related to the parent austenite with the Kurdjumov-Sachs relationship and accompanies the surface reliefs. ε carbide particles precipitate mainly after the ferrite subunits formation or after the coalescence of them. Therefore, the carbide precipitation is not a fundamental characteristic of bainite transformation but is a secondary effect. ε carbide needles precipitating within a bainite lath by long time holding are aligned almost parallel to the $\langle 112\rangle_\alpha$ with almost constant intervals and are related to the ferrite by the Jack relationship. These aspects are exactly similar to those in tempered martensite. Such an ε carbide configuration is thought to arise from the precipitation on the dislocations introduced during transformation.

Effect of boron addition on the microstructure of hot-deformed Ti-added interstitial free steel

N. TSUJI et al.

Effect of boron (B) addition and hot-deformation on microstructure of ferrite was studied using Ti-added interstitial free (IF) steels containing different amount of B. It was clarified that bainitic ferrite having typically lath or plate morphology with high dislocation density can be obtained also in plain IF steels by rapid cooling from austenite region. B addition largely affected the austenite-ferrite transformation and the amount of bainitic ferrite increased with increasing B content. Hot-deformation of austenite enhanced the transformation to polygonal or quasi-polygonal ferrite, resulting in decrease of bainitic ferrite. Interrupting compression tests indicated that enhanced transformation by hot-deformation is mainly due to grain refinement of austenite by recrystallization after hot-deformation. The cooling rate after hot-deformation produced the reversed effect of B on grain size of polygonal or quasi-polygonal ferrite. Ferrite grain size slightly decreased with increasing B content in the case of relatively large cooling rate. When the materials were cooled slowly after hot-deformation, on the other hand, the ferrite grain size increased with increasing B content. The coarse ferrite in B-bearing steels had fairly irregular shape of grain boundaries and inhomogeneous grain size, which suggested the contribution of somewhat discontinuous grain growth. This coarsening of ferrite would be responsible for the previously reported fact that B addition lowers Lankford value of cold-rolled and annealed IF steel sheets.

Modelling texture change during the static recrystallization of a cold rolled and annealed ultra low carbon steel previously warm rolled in the ferrite region.

L. KESTENS et al.

An ultra low carbon steel was finish rolled in the ferrite range, cold rolled and annealed. Quantitative analysis of the deformation and annealing textures indicated that high stored energy nucleation was the dominant recrystallization mechanism after a conventional rolling reducion of 75%. When the rolling reduction was increased to 95%, texture formation during recrystallization was controlled by both oriented nucleation and selective growth; this involves the rapid growth of nuclei that display 32°<110>and 38°<111> misorientations with respect to the surrounding matrix. Furthermore, variant selection is of critical importance during selective growth; out of six symmetrically equivalent <110> and four symmetrically equivalent <111> axes, the one chosen is closest to the *maximum shear stress pole* of the sample.

The lower rolling reduction gives rise to a relatively weak and homogeneous <111>//ND fibre texture (max.=6x random). The higher rolling reduction, on the other hand, leads to a much sharper <111>//ND fibre texture (max.= 15x random) with maxima at orientations that display misorientations of 32°<110> and 38° <111> with respect to the component of maximum intensity of the deformation texture(*i.e.* {311}<110>). It is shown that the combined drawability and in-plane isotropy improve with rolling reduction because selective growth controlled recrystallization favours the formation of more suitable textures.

Physical and Mechanical Properties

Influence of copper content of the base steel on the corrosion behavior of nickel-coated steel sheets

T. OHGA et al.

Influence of copper content in a base steel on corrosion resistance of a nickel-coated steel sheet in solutions as strongly corrosive high-acid beverage has been studied, and the following facts were revealed:

Copper addition to the base steel greatly improves the corrosion resistance of the nickel-coated steel sheet in the citric acid and sodium chloride solution. This improvement is resulted from a reduction in the couple current between the nickel and the base steel in the pinholes formed in the nickel coating layer. The reduction in the couple current is considered to arise from shifting corrosion potential of the copper-added steel to the noble direction and increasing in anodic polarization.

The enrichment of copper on the corroded steel surface is considered to bring about great changes in electrochemical properties. The decrease in the couple current between the nickel and the base steel is also obtained under the variation of an area ratio of anode to cathode.

Copper addition to the base steel also gives high corrosion resistance to the nickel-coated steel sheet in the simulated beverages, such as those containing citric acid, citric acid and sodium chloride, malic acid and, lactic acid except containing phosphoric acid.

Correlation among the changes in mechanical properties due to neutron irradiation for pressure vessel steels

K. ONIZAWA et al.

Irradiation hardening and embrittlement of reactor pressure vessel (RPV) steels having different contents of copper and nickel have been investigated as a part of the phase III of IAEA Coordinated Research Program (CRP). Seven kinds of materials which were made by Japanese steel manufacturers for the CRP were used. Neutron irradiation was conducted in Japan Materials Testing Reactor (JMTR). Mechanical properties of the materials were examined by conducting the hardness, tensile, Charpy impact and fracture toughness tests before and after irradiation. Some relationships between the changes of the mechanical properties due to irradiation were established. The increase in yield strength was correlated with hardness increase and the shift of Charpy transition temperature. In the upper shelf temperature range, the decrease in fracture toughness was well correlated with the degree of the increase in yield strength.