Fundamentals of High Temperature Processes

The surface tension of liquid iron containing nitrogen and oxygen

J.ZHU et al.

The surface tension liquid of Fe–N, Fe–O and Fe–N–O alloys was measured with sessile drop method at 1 823 K. The effect of nitrogen, oxygen and coexistent nitrogen and oxygen on the surface tension of liquid iron was investigated. The results show that both nitrogen and oxygen are surface-active elements in the liquid iron. The surface tension of liquid iron decreased with increasing nitrogen and oxygen contents. The surface-active nature of nitrogen decreases with increasing of oxygen content.

The variation of surface tension with the activity of the surface-active elements was obtained as follows:

Fe–N alloy: $\sigma = 1\,930 - 267\ln(1+45a_N)$, [O]=20–30 mass ppm

Fe–O alloy: $\sigma = 1\,990 - 318\ln(1+130a_O)$, $P_{N_2} = 3.1\times10^{-5}$ atm

Fe–O–N alloy: $\sigma = 1\,990 - 318\ln(1+130a_O)(-282-7\,636a_O-83\,152a_O^2)\ln(1+45a_N)$

Bubble behavior and heat transfer in preheated gas injection into liquid bath

S.V.KOMAROV et al.

Heat transfer between gas bubble and liquid bath has been studied by using cold models. The rising bubble diameter, velocity and the heat efficiency were measured to explain the mechanism of the heat exchange for various gas–liquid systems.

Preheated gas (N_2, He, Ar–He mixture) was injected into the bath of volatile (water) or non-volatile (ethylene glycol, methyl carbitol and ethylene glycol-glycerin mixture) liquid. It is shown that liquid surface tension, gas density and gas temperature are of great importance in determining the bubble diameter. The heat efficiency increases as the bath depth increases and the gas flow rate decreases. The heat exchange is found to be controlled by the heat transfer within the gas bubble.

A model describing time variations in the average temperature and the vapor content has been developed. The computed and measured results reveal that the heat transfer is enhanced with thermal conductivity of gas in the case of gas injection into non-volatile liquid. However, when gas is injected into volatile liquid, the heat efficiency must be considered with accounting for the heat transfer and the vaporization proceeding concurrently.

Ironmaking and Reduction

Production of iron carbide from iron ores in a fluidized bed

S.HAYASHI et al.

Utilizing an ordinary bubbling fluidized bed, a batch of hematite ores (0.15–0.21 cm diameter) was reacted at 923–1 123 K with H_2–CO mixtures to synthesize iron carbide. Sulfur of low pressures unable to form FeS was added to the mixtures. For almost all the conditions, roughly one hour treatment yielded conversion of some types of ores fully to iron carbides as mostly Fe_3C, partly accompaning Fe_xC ($x \fallingdotseq 2.5$), dependently of the reaction conditions. It was proved that small amounts of gaseous sulfur led to carbides rather than free carbon or metallic iron as final products. The conditions of high temperature and low sulfur pressure provided high quality iron carbides having nearly 0.03 mass% S as low as conventional reduced irons. Their conversion yields seemed to be almost insensitive to the H_2/CO mole ratio and ore type.

From rate analysis for carburization process obtained in a same reactor, it was supposed that this process has several times higher reaction rates than those measured in the conventional Iron Carbide Process gas.

Process simulation of cupola

N.N.VISWANATHAN et al.

Cupola is a counter current shaft reactor for production of cast iron. The solid charge consisting of coke, pig iron, steel scrap and flux is fed from the top of the reactor and blast is blown radially through the tuyeres. One-dimensional (1-D) models, wherein the governing equations are solved along the axial direction, have been reported in the literature. However, because of radial entry of blast through the tuyeres, incorporation of boundary conditions at the tuyere level poses a major difficulty in 1-D models. In this paper, a pseudo 2-D model for cupola has been proposed in which, the governing equations are employed in 2-D at the tuyere level and 1-D in the remaining portion. The solution of 2-D equations at the tuyere level generates the appropriate boundary conditions for the remaining 1-D portion above the tuyeres. In order to evaluate the performance of the pseudo 2-D model, a 2-D model was also developed. Further, the two models have been validated using reported experimental data. The study shows that the overall temperature and composition distributions obtained from the pseudo 2-D model are quite comparable with that obtained from the 2-D model. Also, the pseudo 2-D model was found to be computationally faster compared to the 2-D model. Hence, for practical design and operation exercise, pseudo 2-D model can be effectively used.

Sintering of blends containing magnetite concentrate and hematite or/and goethite ores

L.X.YANG et al.

Many sinter plants in China use magnetite concentrate and imported sintering fines in their blends. It has been found that sintering performance is improved with the addition of the sintering fines.

This work studies sintering behaviour of a hematite ore (Ore B) and a geothite ore (Ore C) in blends containing 50–70 mass% concentrate. With addition of 3 mass% burnt lime, sintering performance improves with increasing Ore B or Ore C level in the blend. Partial substitution of Ore C for Ore B in the blends did not cause significant changes in major sintering parameters.

Granulation was identified as the key issue in sintering of such blends. A method to improve granulation efficiency was proposed, which involves pre-granulating the sintering fines and a part of the concentrate, and then granulating the pre-granulated materials with the rest of mix. It has been found that by using the pre-granulation technique, the productivity for blend composed of 50 mass% magnetite concentrate and 50 mass% Ore C increased from below 30 t/m^{2}d to around 40 t/m^{2}d at unchanged mix moisture levels. The technique also led to rises of various extent in productivity in sintering of blends containing magnetite concentrate, Ores B or/and C. The chief reason for this is that the improved granulation efficiency improves bed permeability and shortens sintering time. The sintering results for blends containing 50 mass% magnetite concentrate and 50 mass% Ore B or 50 mass% Ore C by adding 3 mass% burnt lime and using the pre-granulation technique are comparable to a blend composed of 100 mass% fines (no concentrate).

The sinter RDI is generally low and the sinter reducibility is improved by adopting the pre-granulation technique.

Pyrometallurgical separation of boron from iron in ludwigite ore

S.LIU et al.

Laboratory scale experiments and industrial scale tests have been performed in order to develop a new pyrometallurgical process for the separation of boron from iron in ludwigite ore. The results indicate that boron can be effectively separated from iron in ludwigite ore meantime two products can be got. The boron-containing pig iron can be a good substitute for the expensive boron alloys to produce B-series wear resistant cast while the boron-rich slag can be used to extract borax or boric acid.

Steelmaking and Refining

Model study of fluid flow phenomena in a bottom blown bath in the presence of reverse emulsification

M.IGUCHI et al.

Model experiments were carried out to elucidate the behavior of rising bubbles and resultant liquid flow motion in a cylindrical bath agitated by central bottom gas injection. Emphasis was placed on the bubble and liquid flow characteristics in the presence of reverse emulsification, *i.e.*, the slag droplets formation in the lower metal layer. Silicone oil and n-pentane were used as models of top slag and water was used as a model of molten metal. A thin top oily liquid layer was placed on a pool of water. Air was injected through a central single-hole bottom nozzle. The bubble and liquid flow characteristics for the top silicone oil layer were modulated significantly from their respective characteristics in a water bath without a top oil layer. On the other hand, these two characteristics for the n-pentane layer were not influenced by the top oil layer at all inspite of the occurrence of the reverse emulsification. The difference of the bubble and liquid flow characteristics between silicone oil and n-pentane layers can be explained by the fact that the fluid flow resistance at

the silicone oil/water interface is much larger than that between the n-pentane/water interface.

Casting and Solidification

Removal of inclusion through bubble curtain created by swirl motion in submerged entry nozzle

S. YOKOYA et al.

In the steel-making processes, it is well known that suspended non-metallic inclusions can be removed by Ar gas bubbles injected in the steel baths. This study aims to remove the inclusions through a bubble accumulated zone (namely, bubble curtain) created by swirling motion imposed on the flow in a submerged entry nozzle. The results obtained through water model experiments and numerical calculations (Eulerian/Lagragian, Eulerian/Eulerian method) show as follows; the swirling motion works effectively to form a bubble curtain through that all the flow pass, and the half vertical angle of the bubble curtain increases with the increasing swirl strength. On the other hand, inclusions pass nearly parallel to the axis of the submerged entry nozzle, the trajectories of them being similar to the liquid-phase flow pattern. Therefore, a chance for a bubble and an inclusion to meet with each other would significantly increase.

Effect of cooling rate on ZST, LIT and ZDT of carbon steels near melting point

Y.M. WON et al.

The effect of cooling rate on the characteristic temperatures such as liquidus temperature (TL), zero strength temperature (ZST), liquid impenetrable temperature (LIT) and zero ductility temperature (ZDT) has been investigated by calculating the non-equilibrium pseudo binary Fe–C phase diagram. The effect of cooling rate on TL was not significant. The effect of cooling rate on ZST, LIT and ZDT was significant due to segregation of solute elements at the final stage of solidification. Using the microsegregation analysis proposed by Ueshima, the calculated temperatures at the solid fractions of 0.75 and 0.99 corresponded to the experimentally measured ZST and ZDT, respectively. Prediction equation on ZST, LIT and ZDT, which can take into account cooling rate and steel composition, was proposed. At given steel compositions and cooling rates, the suggested prediction equation on ZST, LIT and ZDT could successfully describe the experimentally measured data and the calculated data from microsegregation analysis.

Physical metallurgy of pulsed current submerged are welding of steels

I. HRIVNAK

The low frequency pulsed current was applied in submerged arc welding of structural steels. This process requires a proper welding flux selection. The effect of pulsed current on weld metal solidification and structural transformations was investigated on bead-on-plate tests using various parameters of pulsed current. The latent heat of solidification can affect the microstructure of weld metal as well as that of heat affected zone. Declination of primary grains in transition between pulses was recorded. Recrystalisation and in some cases also grain coarsening was observed in precedent pulses. In 0.5% Mo welds the MA constituent was mostly decomposed. The submerged arc pulsed current welding was applied in real welds with success. The observed shrinkage was less by 30–40% and the notch toughness of weld metals was considerably higher. The geometrical characteristics of the weld, the microstructure and weld properties are found to be largely governed by the pulse welding parameters.

Effect of technological factors on strip profile in twin-roll casting process

N. ZAPUSKALOV et al.

Scientific and technical progress is presently impossible without the application of a new generation of materials with unique properties. Fine-grained alloys, obtained by rapid solidification technique in twin-roll casting process, belong to this class of materials. The commercial success of the twin-roll casting technique depends on the quality of its cast products, first of all on the cross-sectional shape of the strip. Otherwise, an additional post treatment of the as-cast strip such as cold rolling can deteriorate the unique properties of the strip.

To gain a better understanding of the influence of technological parameters on the cross-sectional shape of the strip, a laboratory-size twin-roll casting process has been investigated both theoretically and experimentally. It was found that the geometry of the nozzle slot, the roll sleeve thickness, diameter and length of the roll and the pressure profile between the rolls may influence the cross-sectional shape of the strip. Increasing the nozzle slot length, the flow rate and the distance between the nozzle and the melt bath surface increases the probability of formation of the thickness non uniformity across the strip width. The design of the roll plays a major role in the formation of the cross-sectional shape of the strip: a convex profile is produced by bending of the rolls whilst a concave profile results from thermal expansion of the rolls, in the case of a thick, water-cooled sleeve. The shape of the pressure profile between the rolls depends on the ratio strip width to roll length. Optimisation of the sleeve thickness, diameter and length of the roll is one of the possible ways of improving the cross-sectional profile and the flatness of the as-cast-strip.

Microstructure

Secondary recrystallization of the nitrided Fe–3%Si alloy

J.S. WOO et al.

Nitrided primary specimens containing 0.07% Bi were coated with MgO and annealed in 5%H_2–N_2 (Box annealing). The magnetic induction (B_8) after Box annealing increased with increasing primary recrystallized grain size and decreased with increasing initial nitrogen content. The same primary recrystallized specimens were intermittently annealed in 100% N_2 without MgO coating (Model annealing). B_8 was measured at each annealing. The onset temperature of the secondary recrystallization (T_{cr}) was detected by a steep raise of B_8. The maximum B_8 decreased with increasing T_{cr} from 1 075 to 1 100°C. The initial grain size and nitrogen content for the maximum B_8 was different in both annealing methods. This difference was explained on the assumption that T_{cr} mainly determines B_8 in both annealing methods.

The direct effect of Bi on the selective growth of sharp Goss orientation was small. Bi worked as an inhibitor for grain growth in the primary recrystallization annealing stage.

Physical and Mechanical Properties

Modelling the effect of carbon content on hot strength of steels using a modified artificial neural network

L.X. KONG et al.

The hot strength of austenitic steels with the carbon content varying from 0.0037 to 0.79 wt% was modelled using artificial neural networks (ANN). The carbon content has a complex effect on flow strength of austenite. An increase in carbon content reduces the flow stress of the steels at high temperatures and low strain rates, while it increases the flow stress at low temperatures and high strain rates, especially at low strains. In addition, increasing carbon to above 0.4 wt% dramatically reduces the peak strain for the initiation of dynamic recrystallisation at high Zener–Hollomon parameter, Z. Given the complexity of the deformation and recrystallisation behaviours of these steels, no phenomenological or simple empirical models are able to predict the flow stress over the full carbon range. In this work, the back error propagation algorithm of the ANN model with one hidden layer bias was used, with the number if hidden nodes optimised. The data up to a strain of 4 were used to predict the strength in both work hardening and dynamic recrystallisation regimes. The training speed was an important parameter and was optimised by trimming the data set and learning procedures. The effects of the carbon content on flow stress, peak strains and peak stresses observed from the experiment were accurately represented. However, it was found that the training data set also needed to be optimised to accurately predict the hot strength of the steels.

Strengthening mechanisms in vanadium microalloyed steels intended for long products

S. ZAJAC et al.

The present work has concentrated on the roles of vanadium, nitrogen and carbon in controlling the microstructures and strength of steels designed for hot rolled long products. Effects of cooling rate and additional microalloying with titanium have also been included.

The degree of precipitation strengthening of ferrite at a given vanadium content depends on the available quantities of carbon and nitrogen. The nitrogen content of the ferrite is approximately the same as that of the austenite from which it forms, *i.e.* the total nitrogen content in steel. It was confirmed that nitrogen is a very reliable alloying ele-

ment, increasing the yield strength of V-microalloyed steels by some 5 MPa for every 0.001% N, essentially independent of processing conditions.

Carbon content, on the other hand, has usually been considered not relevant to precipitation strengthening when the precipitation occurs in ferrite because of the very small carbon content in solution in ferrite at equilibrium. We demonstrate that the effective carbon for precipitation in ferrite may be much greater than this during the period of phase transformation, which in turn has a great effect on precipitation strengthening. Such behaviour is explained on the basis that the activity of carbon in ferrite is abnormally high in the presence of undercooled austenite and before cementite nucleation so that profuse nucleation of vanadium carbonitride is encouraged. This new mechanism for precipitation is particularly significant for medium carbon steels typically used for hot rolled bars and sections.

The total carbon content of the steel also contributes to the yield strength by increasing the volume fraction of pearlite. It is shown that the contribution from pearlite is stronger than generally recognised.

Social and Environmental Engineering

Effect of dimethyl ether synthesis on methanol- and iron-making integrated system

S.MACHIDA et al.

In a previous study the catalysts for synthesizing dimethyl ether ($(CH_3)_2O$, DME) from blast furnace gas were successfully developed for increasing methanol (CH_3OH, MeOH) yield. The objective of this study is to design a new MeOH–Iron production system through DME synthesis based on the results, to evaluate a system from exergy concept and to compare with a previously proposed MeOH–Iron production system. Then, effect of the systematic combination and auxiliary fuel: injections to a blast furnace on exergy consumption in the system was mainly assessed.

As a result, the exergy consumption of the new system for hot-metal production became 10% lower than the previous one. At the same time, its exergy consumption for MeOH production decreased as much as 36% of the previous one, showing thermodynamic advantage of DME synthesis. The amount of MeOH production had great dependence on a kind of auxiliary fuels through top gas composition of a blast furnace (BF). It was concluded that MeOH production with DME synthesis and the injection of COM or PC to BF was best systematic combination for maximizing MeOH production from BF offgas.