（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Fundamentals of High Temperature Processes

Derivation of shrinking core model for finite cylinder

J.Moon et al.

A model has been developed to describe the shrinking core style conversion of a solid finite cylinder by gas. The model describes the three limiting cases of gas film diffusion, product layer diffusion and chemical reaction controlled kinetics. The model is validated with experimental data obtained from literature. Rate constants obtained are similar to those from literature.

(cf. *ISIJ Int.*, **41** (2001), 1)

Ironmaking

Experimental investigation of liquid flow shift due to gas cross flow in non-wetted packed beds

D.Y.Liu et al.

An experimental study has been carried out for the gas–liquid two-phase flow in a packed bed simulating conditions of the gas and liquid flows in the lower part of blast furnace. The localised liquid flow phenomenon in presence of gas cross flow, which usually occurs around the cohesive zone and raceway in blast furnace, was investigated in detail. Such liquid flow is characterised in terms of liquid shift distance or liquid shift angle that can effectively be measured by the experiments involved in the current study. It is found that liquid shift angle does not significantly increase or decrease with different packing depth. This finding supports the hypothesis of the force balance model where a vectorial relationship among acting forces, *i.e.* gas drag force, gravitational force and solid–liquid friction force, and liquid shift angle does exist. Liquid shift angle is inversely proportional to particle size and liquid density, and proportional to square of gas superficial velocity, but is almost independent on liquid flowrate and liquid viscosity. The gas–liquid drag coefficient, an important aspect for quantifying the interaction between gas and liquid flows, was conceptually modified based on the discrete feature of liquid flow through a packed bed and evaluated by the combined theoretical and experimental investigation. Experimental measurements suggest that the gas–liquid drag coefficient is approximately a constant ($C'_{DG}=5.4\pm1.0$) and is independent on liquid properties, gas velocity and packing structure. The result shows a good agreement with previous experimental data and prediction of the existing liquid flow model.

(cf. *ISIJ Int.*, **41** (2001), 10)

Numerical analysis of multiple injection of pulverized coal, prereduced iron ore and flux with oxygen enrichnent to the blast furnace

J.A.deCastro et al.

This paper introduces a modeling of the co-injection of pulverized coal, pre-reduced iron ore and flux into the blast furnace through the tuyere. This model treats the blast furnace as a multi-phase reactor. The pulverized coal and pre-reduced fine ore/flux have different chemical and thermophysical properties, thus these materials are treated as separate phases. Therefore this model considers six phases: gas, lump solids (iron ore, sinter, pellets and coke), pig iron, molten slag, pulverized coal and pulverized iron ore/flux. Conservation equations for mass, momentum, energy and chemical species are solved simultaneously based on the finite volume approach. Two operational practices are investigated. One is the injection of pre-reduced fine iron ore and pulverized coal, and the other is the co-injection of pre-reduced fine ore, flux and pulverized coal. The simulation results have contributed to better understanding the blast furnace phenomena with multiple injectants, and supported new improvements in the blast furnace operation. With this model, the injection of pulverized iron ore and flux together with pulverized coal has been proved to be possible at high rates keeping stable blast furnace operation. Moreover, the silicon content can be lowered and the furnace productivity can be largely increased.

(cf. *ISIJ Int.*, **41** (2001), 18)

Forming Processing and Thermomechanical Treatment

Influence of the dimensional change, and its dispersion, on the fabrication size tolerances of austempered ductile iron (ADI) parts: comparison with SAE 4140 steel

M.D.Echeverria et al.

To accurately satisfy the size tolerance of metallic parts, it is necessary to take into account the dimensional change (DC) caused by heat treatment, and the dispersion (ΔDC) of the DC values. The information available on this topic for ADI is very scarce.

The present work aims to determine DC and ΔDC on ADI and SAE 4140 steel parts and to analyze its influence on the size tolerances. Ductile iron and SAE 4140 steel specimens were used to compare DC and ΔDC caused by austempering, and quenching and tempering heat treatments. DC and ΔDC were also measured for several industrial parts of different ADI grades, having different chemical compositions, shapes and sizes.

The results show that in average ADI suffer greater DC than SAE 4140 steel parts of similar mechanical properties, but, on the other hand, ΔDC is always lower for ADI than for steel.

A more accurate prediction of the DC is then possible on ADI than on steels. This would allow the use of less strict machining tolerances, under better machinability conditions, when final operations can be done before heat treatment, producing series of ADI parts. This represents a technical and economical advantage for ADI in comparison with steel.

The influence that the previous microstructure, the austempering temperature and the piece anisotropy, exert on the DC of ADI were also studied. The effects identified in this work are in agreement with previously reported results.

(cf. *ISIJ Int.*, **41** (2001), 25)

Analytical and experimental investigations into microstructure evolution in hot bar stretching

O.L.Jimenez et al.,

Transition in austenite grain size distribution after hot forging, which is closely related to recrystallization, is investigated. Rapid change in grain size distribution just after hot bar stretching is experimentally obtained by hot compression test with controlled rapid quenching, and experimental results are examined by microstructure analysis using incremental approach with three-dimensional finite element analysis for plastic deformation. Through investigation, it has become clear that transient change in microstructure is very rapid with higher amount of plastic deformation. Microstructure analysis using incremental approach with three-dimensional finite element analysis for plastic deformation is helpful to evaluate rapid change in cross-sectional grain size distribution after hot bar stretching.

(cf. *ISIJ Int.*, **41** (2001), 31)

Relation between deformability and microstructures in a commercial pure Ti sheet subjected to dual-temperature square-shaped deep drawing

J.-M.Liu et al.

Recent studies indicated that the deep drawing process at dual-temperatures could extend the drawability in many materials. This paper reports the study of commercial pure Titanium (CP-Ti)(α-Ti) heated to the temperature range of 25–400°C and deep-drawn by water-cooled square-shaped punch. The CP-Ti exhibits almost triple drawability when the temperature is increased from room temperature to 400°C. The location of the fracture point of CP-Ti sheets is on the corner of the cup wall near the die throat. The poor drawability at low temperature is due to the strain-hardening caused by reorientation bands (RBs). The active slip system at elevated temperature promotes the drawability of CP-Ti. The X-ray diffraction studies show the tendency of slip system to be active on the prismatic plane at ~200°C and on the pyramidal plane at ~400°C. The process at 400°C shows the microstructure with the micro-shear bands (MSBs) intersection induced by the heated die and the cooled punch. The MSB-MSB intersection prevents the further thinning of the cup wall and results in the superior deep drawability by virtue of better ductility.

(cf. *ISIJ Int.*, **41** (2001), 37)

Welding and Joining

The effect of vanadium and niobium on the properties and microstructure of the intercritically reheated coarse grained heat affected zone in low carbon microalloyed steels

Y.Li et al.

Four steels, C–Mn–0.05V, C–Mn–0.11V, C–Mn and C–Mn–0.03Nb, all essentially boron-free were subjected to processing to simulate the microstructure of a coarse grained heat affected zone (GC HAZ) and an intercritically reheated coarse grained HAZ (IC GC HAZ). This involved reheating to

1 350°C, rapid cooling ($\Delta t_{8/5}$=24 s) to room temperature and then reheating to either 750°C or 800°C. The toughness of the simulated GC HAZ and IC GC HAZ was assessed using both Charpy and CTOD tests and the hardness of both zones was also measured. A detailed assessment of the size and area fraction of martensite–austenite (M-A) phase in the IC GC HAZ in the steels was obtained from a combination of Scanning Electron Microscopy (SEM) and Image Analysis of the resultant SEM micrographs. In addition, the distribution of the M-A phase was examined by observing 250 fields at a magnification of 2 500 times in the SEM for each of the steels.

It is clear that the alloying addition has a significant effect on the amount and size of the M-A phase. The addition of 0.05% V to the C-Mn steel resulted in the lowest IC GC HAZ Charpy 50J impact transition temperature and the 0.1 mm CTOD transition temperature. The corresponding size and area fraction of the M-A phase were the smallest of the four steels. Raising the level of vanadium to 0.11% caused a deterioration in IC GC HAZ toughness, which was reflected in a greater area fraction of M-A phase, larger mean and maximum sizes of M-A particles and significantly more fields containing M-A phase. The addition of 0.03%Nb produced poorer IC GC HAZ toughness data than C–Mn–V and C–Mn steels and this was related to the large size and area fraction of M-A phase quantified in the Nb steel. The presence of M-A phase is considered to be the dominant factor in determining the toughness of IC GC HAZ.

(cf. *ISIJ Int.*, **41** (2001), 46)

Surface Treatment and Corrosion

Effect of sandblasting on the oxidation and corrosion behaviour of an oxide-dispersed strengthened (ODS) FeCrAl alloy

M.C.Garcia-Alonso et al.

Metallic biomaterials are preferred for replacements of the hard tissues since they are the most suitable to withstand the mechanical loads. For same components the higher surface roughness is preferred to increase the adherence and anchorage between the implant and the bone. In this work sandblasting prior to the oxidation is used to increase the surface roughness of the oxide dispersion strengthened (ODS) FeCrAl alloy. The effect of sandblasting on its oxidation and corrosion behaviour is studied. As a comparison, polished samples are also studied. The alloy treated at 1 100°C generates a dense α-alumina layer which thickness increases with increasing exposure time, being the values somewhat lower for the sandblasted samples. Impedance diagrams obtained for sandblasted samples preoxidised for 1 and 3 h show impedance values at the lowest frequency two orders of magnitude lower than those for polished samples. This decrease in the impedance value can be attributed to the presence of paths or fine cracks in the alumina layer that communicate the aggressive medium with the metallic substrate. Spallation of the alumina layer in preoxidised sandblasted samples has been detected by electrochemical impedance spectroscopy for treatment times of 10 and 100h. Despite this loss of the scale integrity, the corrosion behaviour is good.

(cf. *ISIJ Int.*, **41** (2001), 56)

Transformations and Microstructures

The dynamic, static and metadynamic recrystallization of a Nb-microalloyed steel

S.-H.Cho et al.

Using hot torsion tests, the dynamic (DRX), static (SRX) and metadynamic (MDRX) recrystallization characteristics of a Nb-microalloyed steel were studied. The torsion tests were carried out at temperatures in the range 850 to 1 050°C with strain rates ranging from 0.5 to 5/sec. At the higher temperatures, the Nb remained in solution, while precipitation was underway in the lower temperature range. The results indicate that Nb precipitation has little influence on the value of the critical strain (ε_c) for dynamic recrystallization. The peak strain/Zener–Hollomon parameter equation is derived and the effect of austenite grain size on the peak strain is considered. The times for 50% recrystallization for static and metadynamic recrystallization were established by means of interrupted torsion tests and are compared. The rate of metadynamic recrystallization increases with strain rate and temperature and is observed to be independent of the pass strain; this contrasts sharply with the observations for static recrystallization. Finally, an example is given of an industrial rolling process in which DRX/MDRX can play important roles. Here, the occurrence of dynamic/metadynamic recrystallization causes the load to drop or else to increase less rapidly than in the case of pure strain accumulation in the absence of SRX.

(cf. *ISIJ Int.*, **41** (2001), 63)

The effects of superheating on texture and microstructure of Fe–4.5wt%Si steel strip by twin-roll strip casting

J.Y.Park et al.

Fe–4.5wt%Si strips were produced using a vertical type twin-roll strip casting process. The effect of superheat on the microstructure and texture was studied through thickness direction of the as-cast strips. The heterogeneity of texture and microstructure through thickness direction of the strips was observed. In the case of superheat 20°C, Goss texture evolved between the subsurface and the middle layer and major rolling texture with minor solidification texture evolved in the center layer. In the case of superheat 30°C, solidification texture of $\{100\}\langle uvw\rangle$ fiber evolved from the surface to the center layer.

(cf. *ISIJ Int.*, **41** (2001), 70)

Mechanical Properties

Micromechanical modeling of ductile crack initiation behavior of two phase steels

N.Ishikawa et al.

The effects of the volume fraction and the morphology of a second phase on ductile crack initiation behavior were determined by notched round bar tensile specimens using ferrite–pearlite steels which contain quite small amounts of MnS inclusions. Nominal strain to crack initiation was increased by decreasing pearlite volume fraction, and by the controlled rolling, which produces an elongated microstructure. The Gurson–Tvergaard (G-T) constitutive model was used to investigate the micromechanism of ductile crack initiation behavior. For evaluating the void nucleation strain, an axisymmetric unit cell model based on a Voronoi tessellation of the BCC lattice (V-BCC model) was applied to determine the microscopic strain inside the pearlite phase which controls secondary void nucleation. The parameter representing the volume fraction of nucleated void, f_N, was evaluated by fitting the numerical solution to experimental data for nominal stress/nominal strain curves of the notched round bar specimen. It was found that steels with lower pearlite volume fractions or elongated pearlite nodules have lower f_N, and the void growth rate is lower for the steels with lower f_N, which requires a large amount of plastic strain for void growth. Ductile cracking was initiated in the region having the highest void volume fraction for all steels. It was shown that the critical void volume fraction for ductile crack initiation is independent of stress triaxiality, and the steels with lower f_N show smaller critical void volume fractions.

(cf. *ISIJ Int.*, **41** (2001), 76)

Social and Environmental Engineering

Macroscopic behaviors of dioxins in the iron ore sintering plants

E.Kasai et al.

The emissions of dioxins to the environmental air from iron ore sintering plants become to be regulated by the new Japanese law against dioxins. The emissions from Japanese sintering plants have been already fairly low levels by large efforts made so far for their reduction. However, substantial and systematic countermeasures are not yet developed and, further, detailed information has not been available on the formation/decomposition of dioxins in the sintering plant.

In the present investigation, two different plants were chosen and samplings were made for gaseous, liquid and solid materials at various positions of the processes. Concentrations of dioxins and other compounds of the samples were analyzed. Understanding of the characteristics of the dioxins formation in the sintering process has been attempted on the basis of the analytical results. Macroscopic behavior of dioxins in the sintering and waste gas treatment processes is discussed. Further, the results of the plant test obtained with and without use of recycling materials are reported.

(cf. *ISIJ Int.*, **41** (2001), 86)

Effect of additives on the dioxins emissions in the iron ore sintering process

E.Kasai et al.

As an initial step of collaborative studies carried out by the SDD project, some series of sinter-pot tests were carried out to examine formation/decom-