Casting and Solidification

The influence of composition on the hot ductility of steels and to the problem of transverse cracking (Review)

B.MINTZ

A review of the literature has been made, concentrating on the influence of N, V, Ti and the residuals, Cu, Sn, S and P, on the hot ductility of steels.

Nitrogen is generally detrimental to ductility in Al containing and microalloyed steels; to avoid transverse cracking the N levels should be kept as low as possible. When Ti additions are made to low N, C–Mn–Al steels, (0.005% N) the best ductility is likely to be given by a high Ti : N ratio of 4–5 : 1. For high N steels (0.01% N), a low Ti level (0.01%) is recommended to reduce the volume fraction of Ti containing particles, but allow precipitation to occur at high temperatures. In addition a low soluble Al level is needed to prevent the excess N from combining to form AlN. For C–Mn–Nb–Al steels, similar recommendations can be made with regard to adding Ti. However, the presence of Nb and Al appears to have little influence on the ductility, since these elements coarsen the Ti containing precipitates. Furthermore, once the Ti has combined with the N any remaining N now seems beneficial, possibly because high N contents encourage precipitation at higher temperatures.

V as a microalloying addition gives better hot ductility than Nb and the product of the V and N has to approach 1.2×10^{-3}, *e.g.* 0.1% V and 0.012% N before ductility deteriorates to that normally shown with a 0.03% Nb addition.

S levels should be kept low to reduce the detrimental precipitation of fine sulphides at the γ boundaries. Care must be taken with Ca treatment as if the steel is too "clean", none of the Nb may be able to precipitate out prior to straightening.

Residual levels of Cu>0.15% and Sn are detrimental to surface quality and encourage transverse cracking. It is found that Cu is deleterious to ductility, but Ni can be added to compensate for this loss. It is recommended that the amount of Ni added should be greater than the residual Cu level to be sure of avoiding problems, (Ni : Cu ratio nearer to 1.5 to 2).

Phosphorus although potentially beneficial to ductility can not be recommended unless its segregation during solidification can be reduced.

Forming Processing and Thermomechanical Treatment

Distinctive aspects of the physical metallurgy of warm rolling (Review)

M.R.BARNETT et al.

Warm, or ferritic, rolling is gaining in popularity amongst steel makers as a means of cutting the cost of steel production and opening up the window of hot band properties. The current work presents an overview of some of the more unique, but important, metallurgical aspects of the process. These have been highlighted in a number of laboratory studies that have been conducted over the last decade or so and as yet appear not to have been drawn together in a single article. Certain aspects of the industrial practice of warm rolling are also addressed. But it must be noted that these are somewhat sparse in the literature, presumably due to its status as an emerging, as opposed to widely practised, technology.

Transformations and Microstructures

The influence of microstructural aspects on the service behaviour of advanced power plant steels (Review)

H.CERJAK et al.

There is a world-wide substantial demand to increase the application temperature and design stresses of advanced creep resistant ferritic-martensitic 9–12% Cr steels to increase the efficiency of thermal power plants. They show, compared to austenite grades, favourable physical properties—like good thermal conductivity and low coefficient of thermal expansion coupled with better service behaviour. In the frame work of the European research action COST 501 intensive investigations of these types of steels were performed. These alloys show during service conditions pronounced microstructural changes in the aged as well as in the stressed conditions. Therefore an extrapolation of short term creep tests to long times-*i.e.* 100 kh-using conventional methods is not successful because of changes in the acting creep mechanism governed by microstructural development. Therefore an intensive investigation and modelling of the microstructure of W- and Mo-alloyed advanced 9–12% Cr steels, mainly G-X12 CrMoVWNbN 10-1-1, was applied to understand the mechanisms. Hardness tests, optical microscopy, SEM, TEM methods and thermodynamic equilibrium phase diagram calculations were performed. Very promising is the use of the EFTEM (Energy filtering TEM) method to quantify the precipitation sequence of the different types of precipitate: $M_{23}C_6$, MX, Laves Phase and Z-Phase as a function of time, temperature and straining.

A new approach ("Graz Model") was proposed for the improvement of the creep resistant alloys in terms of the α/γ-transformation and the Curie temperature respectively, which influence the microstructural stability. Both were found as important influencing factors.

Experimentally it was found, that the alloys showing the highest creep resistance *i.e.* the Japanese grade NF616/P92 and the alloy B2, one of the COST 501 activity, show the highest degree of microstructural stability after creep exposure.

Further investigations and modelling is necessary to develop an optimised alloy composition of advanced 9–12% Cr steels.

Ironmaking

Factors affecting returned sinter fines regimed and strand productivity in iron ore sintering

R.P.BHAGAT

The paper describes return sinter fines regime and the factors influencing it under the prevailing condition of the sintering plant at Bhilai, India. The effect of return sinter fines, basicity and other variables on the yield of sinter and speed of sintering has been evaluated through the pot sintering experiments designed statistically and empirical equations have been established.

An optimum level of basicity ratio and that of return fines input have been observed for the strand productivity. The basicity ratio and coke breeze content are inter-influenced: greater amount of coke breeze helps in productivity improvement when sintering is carried out at higher basicity level. A greater amount of return fines in the mix (through screening out the −5 mm size fraction from the sinter at blast furnace and its recirculation) decreases the throughput of the fresh material on the sintering strand. However, part of loss is compensated by a simultaneous increase in the yield of sinter.

A numerical study on the combustion of a low temperature-carbonized semi-coke particle

T.MORI et al.

These experiments and numerical simulation were carried out to analyze the transport phenomena in a single semicoke particle burning at the surface in a laminar gas stream. In this study, we developed a mathematical model to predict the transport phenomena in semicoke burning at the surface. The model assumes that the semicoke particle is a packed bed of micro semicoke particles and the combustion of fixed carbon is calculated as the char. The coke pyrolysis is also estimated involving the deposition and decomposition of tar and the combustion of VM (volatile matter). The exchange of heat and mass between the coke particle and gas phase around the particle is calculated simultaneously.

The effect of surface combustion of the single semicoke particle on its property is calculated by the control volume method (CVM). The predicted temperature profiles and mass loss of the particles agree well with experimental data and the CVM analysis shows that the combustion of the semicoke particle is governed by boundary layer diffusion.

Steelmaking

Removal of copper and tin in molten iron with combination of plasma heating and powder blowing decarburization under reduced pressure

T.NISHI et al.

The combination of plasma heating and the powder blowing decarburization method was applied to remove copper and tin, which are "tramp" elements in relation to recycling, from molten iron in a large scale experiment. Plasma heating was adopted as the local heating method and combined with a weak oxidizing powder blowing method under a commonly used reduced pressure of about 0.13–0.65 kPa for their removal.

The results demonstrated that the method could accelerate the efficient removal of copper and tin from iron melted from scrap under a reduced pressure compared with only the powder blowing method. The apparent removal rates of copper and

tin increased as 2–3 times and 4 times much as that without plasma heating. The plasma heating is thought to compensate for the heat loss at the reaction site by this method.

Transformations and Microstructures

Recrystallization–precipitation interaction of two medium carbon niobium microalloyed steels

S.F.MEDINA et al.

Recrystallization-precipitation-time-temperature (RPTT) diagrams for strains of 0.20 and 0.35 have been determined for two microalloyed steels with niobium percentages of 0.024 and 0.058, respectively, and equal percentages of carbon and nitrogen. The method known as "back extrapolation" has been used for the determination of static recrystallization kinetics and also for the plotting of the diagrams. While a single plateau was observed on the recrystallized fraction against time curves for the first steel, as a consequence of strain induced precipitation, these curves for the second steel showed the formation of a double plateau, whose interpretation, confirmed by calorimetric analysis, supposes the formation of two types of precipitates. The work uses transmission microscopy to show the precipitates which are formed in both steels, as well as the size most probably capable of inhibiting recrystallization. Finally, an analysis is made of the RPTT diagrams and of the large amount of information which they offer for designing a more appropriate rolling schedule in order to obtain finer precipitates and a better austenitic microstructure before the austenite → ferrite transformation.

Formation of {111}⟨110⟩ and {111}⟨112⟩ textures in cold rolled and annealed IF sheet steel

M.R.BARNETT et al.

The relative prevalence of {111}⟨112⟩ and {111}⟨110⟩ orientations in the recystallization texture of a partially annealed cold rolled Ti-IF steel was examined using Electron Back-Scattering Diffraction (EBSD) analysis. A disproportionately high number of recrystallized grains with a near {111}⟨112⟩ orientation were observed at the grain boundaries between {111}⟨*uvw*⟩ and {*hkl*}⟨110⟩ deformed grains. It is suggested that the presence of "soft" {*hkl*}⟨110⟩ orientations adjacent to a {111}⟨*uvw*⟩ grain impacts upon the development of the deformation structure in that grain in such a way as to favour the formation of near {111}⟨112⟩ nuclei during recrystallization. It is proposed that the formation of in-grain shear bands is an essential part of this process. This mechanism comprises a new explanation for the link between {*hkl*}⟨110⟩ deformation textures and {111}⟨112⟩ recrystallization textures seen in cold rolled IF steels.

Influence of Ti and N contents on austenite grain size and precipitate size in structural steels

S.F.MEDINA et al.

The austenite grain size of six steels with different Ti and N contents has been determined at 1 300°C×10 min and at 1 100°C×10 min. The most stable grain was achieved for a Ti/N ratio close to 2. In parallel, a study of precipitate sizes was carried out using transmission electron microscopy (TEM) and scanning electron microscopy (SEM). The results indicate that the steels with a lower N content and approximately the same Ti content show a distribution of precipitates of larger size, which increases with the Ti content in solution at the austenitization temperature applied. As the austenitization temperature increases, the double effect of precipitate dissolution and coarsening appears, and only with a hipostoichiometric Ti/N ratio and as precipitated Ti content above 0.010 (wt%) are they capable of controlling the austenite grain up to high temperatures.

Nano investigation on the grain boundary periodic segregation based on the divorced coincident segregation in 5% Ni steels

H.MABUCHI et al.

The segregation mechanism of alloying elements in prior austenitic grain boundaries in the improved 5% Ni steels with no or almost no intergranular fracture was studied for the first time by applying FE-TEM in the previous study. It has been consequently elucidated that alloying elements tend to segregate coincidently to grain boundaries, showing the asymmetric segregation according to solute interactions. The observed behavior was defined as the "divorced coincident segregation" in the previous paper. The result also shows the effect of soluble Al on the suppression of temper embrittlement and hydrogen embrittlement.

In the present study, the mechanism of the divorced coincident segregation is further investigated by employing FE-TEM-EDS along grain boundaries. First is found the periodic segregation of Al and Si, which vary alternately by the cycle of about 3 nm along grain boundaries investigated. It is also shown that Al has the repulsive interaction with Si both in grain boundaries and in matrices.

Effect of trace elements on creep properties of 0.06C–2.25Cr–1.6W–0.1Mo–0.25V–0.05Nb steel

K.MIYATA et al.

The effect of trace elements such as Mn and B on creep properties of 0.06C–2.25Cr–1.6W–0.1Mo–0.25V–0.05Nb has been investigated from the standpoints of a long-term microstructural stability. The chemical analysis of extracted residues and TEM observation show that the $M_{23}C_6$ carbide and/or M_7C_3 carbides, precipitated by tempering are replaced by M_6C with a concentration of W; *i.e.*, the amount of W in solution reduces during creep. On the other hand, MX type carbides such as VC and NbC are very stable during long-term aging and contribute to the creep strength by obstructing the dislocation annihilation.

One of the most significant results is that a reduction in Mn-content lowers the minimum creep rate, resulting in an increase in the creep rupture time. The nucleation and/or growth of M_6C are retarded with reducing Mn-content, thereby the increase in dissolved W seems to enhance the resistance to creep deformation. Another significant result is that an increase in B-content has delayed the transition from the primary creep to a tertiary creep stage. The principal roles of B are stabilizing $M_{23}C_6$ or $M_{23}(C,B)_6$ on former austenite grain boundaries and retarding the dynamic recrystallization during creep. In addition, in the specimens with higher amount of B, the bainite lath interface is covered by MX and some filmy precipitates with high density, thereby the softening resistance is enhanced.

Mechanical Properties

Effect of strain rate and plastic pre-strain on the ductility of structural steels

H.QIU et al.

Ductile fracture processes in structural steels under high strain rates have been investigated by tensile test. Under high strain rate loading, the ductility of the steels decreases. The reasons for this decrease is discussed from the analysis of ductile fracture process, as especially of void nucleation strain and void growth strain up to fracture. A three-dimensional void coalescence model for the high strain rate loading was obtained by modifying Thomason's static three-dimensional void coalescence model. The model was used to predict the void growth strain and evaluate the effect of strain rate on void coalescence. The influence of plastic pre-strain on ductility under high strain rate loading was also investigated.