

Letter

Carbon content of austenite in isothermally transformed 300M steel

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Abstract

Published data on the carbon concentration of retained austenite in 300M steel which has been isothermally transformed to bainite have been analysed using phase transformation theory. It is demonstrated that the chemical composition of the austenite can be predicted by assuming that the growth of bainite occurs without any diffusion, but that the excess carbon is partitioned shortly afterwards into the residual austenite.

1. Introduction

The large silicon concentration of 300M steel [1] retards the formation of cementite; the carbon that is partitioned from bainitic ferrite into the residual austenite stabilizes the latter. Substantial quantities of the austenite are therefore retained to ambient temperature. The martensitic transformation of this austenite under the influence of an externally applied stress is well known to affect the toughness of such steels [2-5]. A key factor controlling the stability of the retained austenite is its carbon concentration. Hence, during the course of some microstructure-mechanical property investigations of bainitic microstructures in 300M steel, Tomita and Okawa [6] measured the carbon concentration of retained austenite in a number of samples. It is demonstrated here that for steels like 300M, the composition of the austenite can in fact be calculated on the basis of the mechanism of bainite transformation.

2. Method

There is evidence that bainite grows like martensite, without diffusion but with the excess carbon being partitioned into the residual austenite soon after the

growth of each bainite plate has ceased [5, 7, 8]. This mechanism of transformation becomes thermodynamically impossible if the carbon concentration of the austenite exceeds that given by the T_0 boundary on the phase diagram. The T_0 boundary represents the locus of points on a temperature-carbon plot where austenite and ferrite of the same composition have identical free energies. The corresponding curve which also allows for the strain energy due to the shape change associated with bainite growth is called the T_0' curve.

We note that if during its growth the bainite never has any excess carbon in solution, then the corresponding composition at which the austenite would cease to transform should be given by the Ae_3' phase boundary. This represents the paraequilibrium $\alpha + \gamma/\gamma$ phase boundary, for the case in which the iron-to-substitutional solute ratio is the same in the ferrite (α) and austenite (γ). During paraequilibrium, the carbon partitions to the extent that it achieves a uniform chemical potential everywhere, subject to the constraint that the substitutional solutes do not redistribute during transformation [5, 9].

To summarize, the formation of bainitic ferrite should cease as soon as the carbon concentration of the residual austenite reaches the T_0' boundary, assuming that carbide precipitation does not also occur and that the bainite reaction is allowed to proceed to its maximum extent. The absence of carbide precipitation is a reasonable assumption for high silicon steels such as 300M.

3. Analysis of experimental data

Three different sources of data were utilized. The results just reported by Tomita and Okawa [6] are based on an X-ray technique in which the carbon concentration of the residual austenite is determined from its lattice parameter and the known relationship between the parameter and the austenite composition.

Ericsson *et al.* [10] measured the isothermal transformation diagram for 300M steel using a magnetometric method. Each of the family of C -curves for bainite had a flat top, which represents the maximum fraction of bainitic ferrite that can form at the temperature corresponding to the flat top. The carbon concentration x_γ of the austenite that remains untransformed can therefore be determined using a mass balance

equation [11]:

$$x_\gamma = \frac{\bar{x} - x_\alpha V}{1 - V} \quad (1)$$

where \bar{x} is the average carbon concentration of the steel, x_α is the concentration of carbon which remains in the bainitic ferrite, a value which is relatively small and assumed to be 0.03 wt.%. V represents the volume fraction of bainitic ferrite.

Finally, we generated some of our own data during the course of some microstructure-mechanical properties work. A sample of 300M steel was homogenized at 1300 °C for 3 days whilst sealed in a quartz tube containing a partial pressure of pure argon. Rods 3 mm in diameter and 12 mm long were austenitized at 1200 °C for 10 min, then quenched into molten tin for isothermal transformation, before quenching in water. The isothermal transformation conditions were 401 °C for 73 h, 403 °C for 30 min and 159 h, and 408 °C for 98 h. The volume fractions of bainite were determined by point counting, which gave 0.46 ± 0.02 , 0.42 ± 0.03 , 0.53 ± 0.02 and 0.48 ± 0.02 using 2000, 2000, 1000 and 2000 counts respectively. These volume fraction data were then substituted in eqn. (1), to determine the carbon concentration of the residual austenite, as plotted in Fig. 1.

The compositions of all the alloys involved are listed in Table 1. Steel A was the steel used in the present

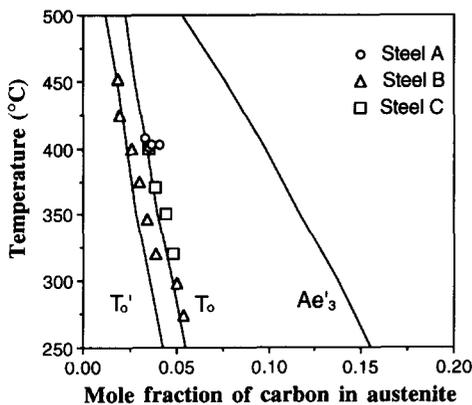


Fig. 1. Calculated phase boundaries for 300M steel together with experimental data representing the carbon concentration of the austenite which is left untransformed after cessation of the bainite reaction.

TABLE 1. Chemical compositions of the three 300M steels (wt.%)

Steel	C	Si	Mn	Ni	Cr	Mo	V	Reference
A	0.44	1.74	0.67	1.85	0.83	0.39	0.04	
B	0.41	1.59	0.79	1.85	0.75	0.43	0.08	10
C	0.41	1.70	0.80	1.76	0.80	0.41	0.08	6

research, and the results obtained were compared with data from the literature (steels B and C). The three steels are in fact very similar; the differences were not found to affect the calculated phase boundaries to any significant extent. The method for calculating the T_0 , T_0' (400 J mol⁻¹ of stored energy) and Ae_3' curves has been presented elsewhere [12].

Figure 1 shows that in all cases, the measured carbon concentrations of the retained austenite are well represented by the T_0 and T_0' curves of the phase diagram. The data should ideally all fall on the T_0' boundary, but plastic accommodation and other effects associated with the trapping of carbon in isolated austenite films [5] means that the average x_γ can vary between the T_0 and T_0' curves. It is notable that in all cases, x_γ is far less than that consistent with the Ae_3' curve, confirming the assumed mechanism of transformation.

4. Conclusions

The fact that the bainite reaction ceases if the carbon concentration of the residual austenite renders diffusionless transformation impossible, can be used to estimate the microstructure of isothermally transformed steels in which carbide precipitation is suppressed. Thus, the composition of any retained austenite can be estimated from the T_0 curve of the phase diagram, which can in turn be calculated as a function of the alloy content of the steel concerned. Since the mechanical stability of the austenite depends on its composition, the thermodynamic technique discussed here can be used to design mechanical properties as demonstrated elsewhere [3, 4].

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References

- 1 T. V. Philip, *Materials Handbook*, ASM, Metals Park, OH, 1983, pp. 421-443, 9th edn.
- 2 R. M. Horn and R. O. Ritchie, *Metall. Trans. A*, 9 (1978) 1039-1053.
- 3 H. K. D. H. Bhadeshia and D. V. Edmonds, *Met. Sci.*, 17 (1983) 411-419.

- 4 H. K. D. H. Bhadeshia and D. V. Edmonds, *Met. Sci.*, 17 (1983) 420–425.
- 5 H. K. D. H. Bhadeshia, *Bainite in Steels*, Institute of Materials, London, 1993.
- 6 Y. Tomita and T. Okawa, *Mater. Sci. Eng.*, A172 (1993) 145.
- 7 J. W. Christian and D. V. Edmonds in A. R. Marder and J. I. Goldstein (eds.), *Phase Transformations in Ferrous Alloys*, TMS-AIME, Warrendale, PA, 1984, pp. 293–326.
- 8 H. K. D. H. Bhadeshia and J. W. Christian, *Metall. Trans. A*, 21 (1990) 767.
- 9 M. Hillert, *Jernkontorets Ann.*, 141 (1957) 757–764.
- 10 C. E. Ericsson, M. S. Bhat, E. R. Parker and V. F. Zackay, *Metall. Trans. A*, 7 (1976) 1800.
- 11 H. K. D. H. Bhadeshia, *J. Phys. (Paris)*, 43 (1982) 443–448.
- 12 H. K. D. H. Bhadeshia and D. V. Edmonds, *Acta Metall.*, 28 (1980) 1265.