The Distribution of Retained Austenite in Martensite and the Influence of Inter-lath Crystallography

H.K.D.H. Bhadeshia and D.V. Edmonds

A series of steels was examined for thin films of austenite trapped between laths/platelets of martensite. The distribution of these films was found to correlate with the inter-lath crystallography. In those steels with almost continuous films of inter-lath austenite the degree of co-operative martensite formation appeared limited. When limited films of heterogeneously distributed austenite were observed, not only was the incidence of twin related laths higher, but austenite was not in general observed between the twin-related laths. In other steels, austenite could not be detected. In these steels the lath packets consisted entirely of twin-related laths. The results are analysed in terms of the degree of mutual accommodation of transformation strains associated with the formation of adjacent martensite variants and the influence of mechanical stabilisation of residual austenite in the absence of mutually compensating accommodation effects.

I. Introduction

In recent years, the study of retained austenite films associated with martensite in low alloy steels has assumed new significance, primarily due to its apparent effect on the mechanical properties of quenched and tempered high-strength steels [1-4]. Due to the relatively high Ms temperatures of low alloy martensites, only thin films of inter-lath austenite are retained at room temperature. However, the reasons for the lack of complete transformation are not clear - even cooling to -196^{o}C often fails to finish the transformation [5,6]. Since such refrigeration fails to give a significant decrease in the amount of retained austenite, chemical or thermal stabilisation has been ruled out as the possible reasons for the anomalous stability of the retained austenite films [6]. Indeed, Mossbauer spectroscopy [7] and X-ray diffraction experiments [5] give no evidence for chemical stabilisation by carbon enrichment of the austenite. While no such enrichment is expected on the basis of the displacive nature of the martensite transformation, partitioning of carbon is feasible either during the quench (i.e. after formation of some martensite) or during subsequent tempering. Hence, although no direct evidence is available, the stability of the retained austenite films has been attributed to mechanical stabilisation [6].

The aim of the present work was to gain a better understanding of the stability of films of retained austenite with the help of transmission electron microscopy. The detailed experimental procedure is discussed elsewhere [4] and is not considered further.

Department of Metallurgy and Materials Science, University of Cambridge, Cambridge, U.K.

II. Results and Discussion

(1) Fe-4Ni-0.4C

A microstructure of lath/platelet martensite was obtained upon quenching from the austenitising temperature. Examination of over 60 electron micrograph/diffraction pattern pairs revealed that approximately 55% of adjacent martensite units had twin related lattices. The structure appeared to be partitioned by large platelets with finer martensite in the partitioned areas (fig.1). The twin related martensite was found mainly in the partitioned regions and occured in two distinct formations. In one situation, the adjacent platelets alternated in twin orientation and formed as clearly defined packets and it was found that retained austenite could not be imaged within these packets (fig.2). When irregular groups of platelets with only some adjacent martensite units being twin related were observed, retained austenite could be imaged between units in the same crystallographic orientation and only to a very limited extent at the interfaces between twin related units. In all cases the retained austenite films were rather discontinuous (fig.3) and it was estimated that the quantity of retained austenite involved is less than 1%. The inhomogeneous distribution of retained austenite can be rationalised if it is considered that the twin related martensite units form in a mutually accommodating manner. In this case mechanical stabilisation of austenite is expected to be mitigated relative to the situation where adjacent variants form in the same crystallographic orientation, when their accommodation effects would be expected to be additive rather than self compensating. Clearly, the compensating effects would be maximised when the twin related platelets can form in regular groups with alternating units. The formation of twin related variants in the regions partitioned by the larger platelets is consistent with the above arguments since such regions would be under the constraint of an already formed rigid martensite frame and a greater degree of mutually compensating accommodation would minimise strains.

(2) Fe-3.9Mo-0.18C

Considerable quantities of inter-martensite retained austenite films could be imaged and it was found that the martensite platelets tended to be in the same crystallographic orientation in space. It is probable that very little mutually compensating accommodation is involved in the formation of such groupings since the shape deformation is expected to be the same for adjacent platelets. In such circumstances the residual austenite would be deformed to a greater extent by the larger resultant accommodation strains, leading to mechanical stabilisation. However, the films of retained austenite proved to be too fine to be able to characterise easily their microstructure (fig.4).

(3) Fe-0.08C-1.1Mn-0.2Si-5.5Ni-14.5Cr-2.1Mo-0.7Nb-1.9Cu

With this alloy the martensite groups again formed in the same crystallographic orientation and the high alloy content allowed the retention of larger quantities of austenite (fig.5). The microstructure of the latter austenite could be clearly resolved and it was interesting to note that the austenite was heavily faulted, with a dominant fault plane aligned with respect to the martensite habit plane trace, as expected when the austenite absorbs a significant proportion of the accommodation strain. Such extensive faulting can be expected to mechanically stabilise the residual austenite to further transformation.

(4) Fe-0.31C-2.0Si

Since retained austenite could not be detected upon direct quenching, an attempt was made to enhance the retention of austenite by thermal stabilisation. The specimen was austenitised at 1100°C for 5 mins followed by a quench to 335°C (a temperature below the calculated Ms of 410°C) where it was held for 1 hour before finally quenching to room temperature. However, retained austenite could not be detected and it was found that the martensite was in classical lath formation (fig.6) with alternate laths being twin related. The lath packets were extremely regular, as illustrated in fig.7. These results are again consistent with twin related martensite forming in a mutually compensating manner.

In view of the above observations, it is concluded that mechanical stabilisation is one of the key factors responsible for the retention of thin films of austenite. In situations where accommodation effects are minimised (as when adjacent twin related martensite formation occurs), the propensity to retain austenite appears to be reduced. Intuitively one would expect a high strain energy interaction, and hence a lower probability of retaining inter-lath austenite, between twin related variants of martensite. This cannot be supported theoretically without a knowledge of the displacement vector (d_1) associated with the shape deformation of each twin variant. The latter may be obtained after application of the phenomenological theory of martensite, when relevant detailed crystallographic data becomes available. However, in the case of alpha martensite found in high alloy steel [8], it is known that twin related laths have shear components of their shape strains that can cancel each other.

III. Summary

The propensity for austenite retention has been rationalised in terms of the local inter-martensite crystallography, and it was found that twin-related martensite variants do not favour the retention of austenite. Inter-martensite retained austenite films were most profuse when the adjacent martensite variants were in the same crystallographic orientation and the results were found to be consistent with a mechanical stabilisation effect which hindered and often prevented complete transformation to martensite.

The authors are grateful to Professor R.W.K. Honeycombe for the provision of laboratory facilities, and for his encouragement during the course of this work, and to the Ministry of Defence (RARDE), Fort Halstead, for their financial support, DVE also wishes to thank the Royal Society for the Warren Research Fellowship.

References

[1] G. Thomas: Iron and Steel International, 46(1973), 2267.
[2] E.R. Parker: Met. Trans., 8A(1977), 1025.
[3] G. Thomas: Met. Trans., 9(1978), 439.
[4] H.K.D.H. Bhadeshia and D.V. Edmonds: Metal Science: 1979, in press.
[5] H.K.D.H. Bhadeshia and D.V. Edmonds: Unpublished research.
[6] B.V. Narasimha Roa, R.W. Miller, G. Thomas: Proc. Int. Conf. Heat Treatment, 1976, The Metals Society, London.
[7] A.L.T. Azevedo and E.G. da Silva: Scripta Met., 12(1978), 113.
[8] P.M. Kelly: Acta Met., 13(1965), 635.

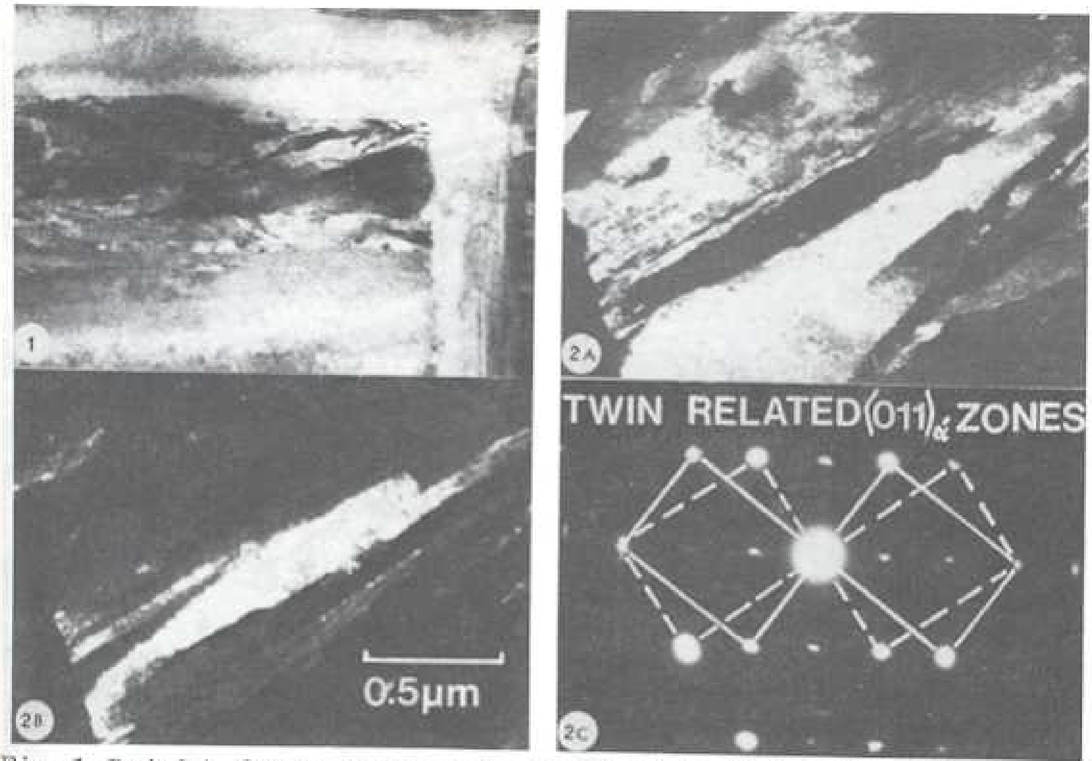
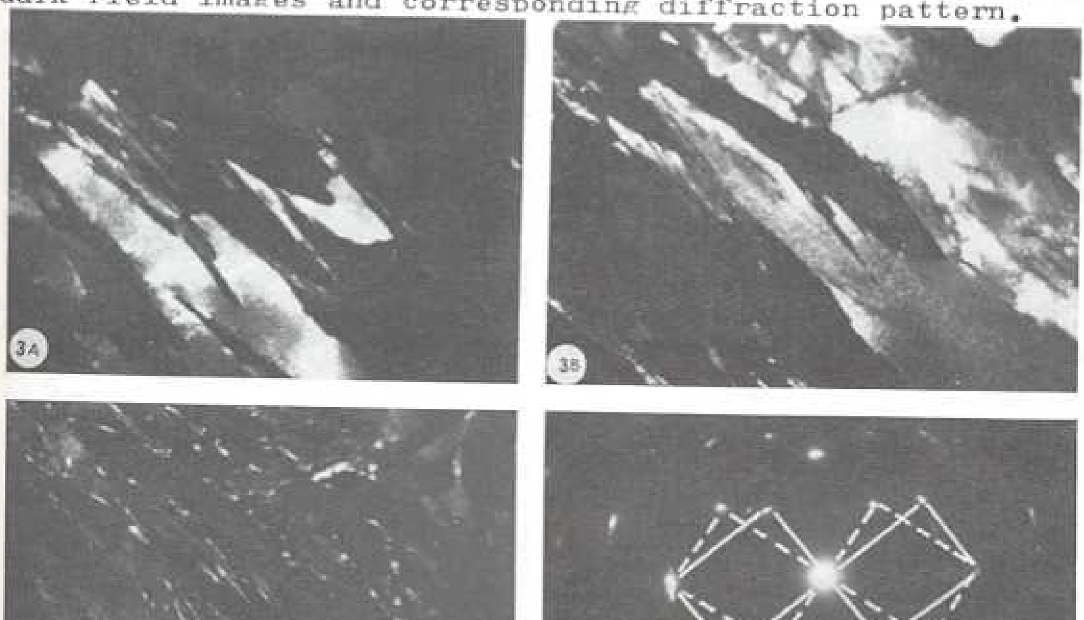


Fig.1 Bright field image of quenched Fe-4Ni-0.4C. Fig.2a,b, c, twin, matrix dark field images and corresponding diffraction pattern. Fig.3a,b,c,d twin, matrix, retained austenite dark field images and corresponding diffraction pattern.



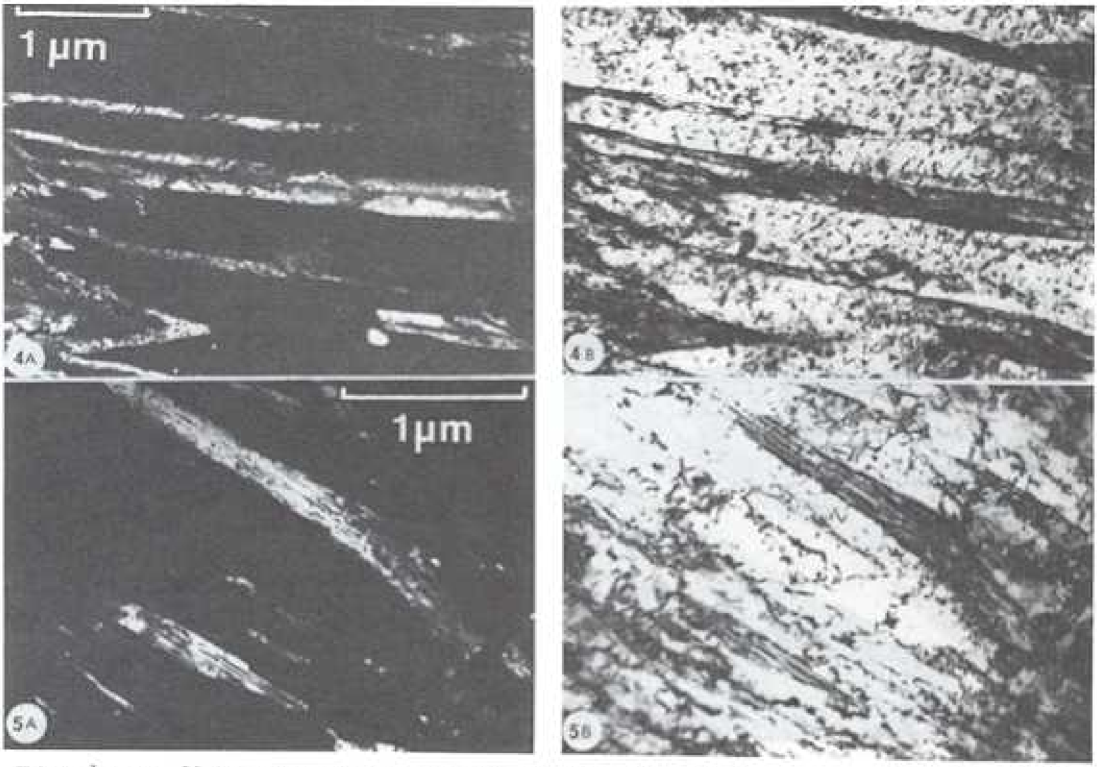


Fig.4a,b γ dark field and bright field images. Fig.5a,b γ dark field and bright field images.Fig.6 Quenched Fe-0.31C 2Si alloy. Fig.7a,b,c twin, matrix dark field images and DP.