Note

TRIP-Assisted Steels?

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1. Introduction

The weight of an automobile can be reduced by using high-strength steels as long as they have the ductility essential in metal-forming operations.[1–3] One class of suitable alloys is known as the "TRIP-assisted steels", in which the microstructure is a mixture of allotriomorphic ferrite and bainite; the term TRIP stands for transformation-induced plasticity. The typical chemical composition is Fe–0.15C–1.5Si–1.5Mn wt%; the high silicon concentration ensures that cementite is not precipitated during the growth of upper bainite. The carbon that is partitioned from bainitic ferrite stabilises the residual austenite, enabling it to be retained at ambient temperature. The final microstructure typically contains 20% bainitic ferrite, 10% retained austenite with the remainder being allotriomorphic ferrite.

There have been many publications on the microstructure and property relationships of TRIP-assisted steels. Most of these studies highlight the presence of the retained austenite and many imply that the observed high uniform elongation is a consequence of the martensitic transformation of the retained austenite under the influence of an applied stress or strain. The purpose of the present work was to investigate theoretically, the magnitude of the contribution that transformation plasticity can make to the total elongation.

2. Method

Like all displacive transformations in steels, the growth of martensite is associated with a shape deformation which is characterised as an invariant-plane strain. The invariant-plane is the habit plane of the martensite. The deformation is a combination of a large shear ($s \simeq 0.26$) parallel to the invariant-plane and a dilatation ($\delta \simeq 0.03$) normal to the plane (**Fig. 1**).

The deformation can be written in matrix form using the basis symbol Z, as follows[4,5]:

$$(\mathrm{Z\,P\,Z}) = \begin{pmatrix} 1 & 0 & s \\ 0 & 1 & 0 \\ 0 & 0 & 1+\delta \end{pmatrix}$$

The effect of the invariant-plane strain on a vector **u** is to change it to another vector **v** which is in general distorted and rotated relative to **u**.

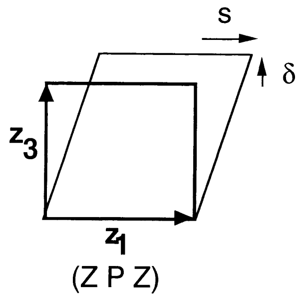

Fig. 1. An invariant–plane strain with a shear s and dilatation δ. The coordinates z_i represent an orthonormal set in which z_3 is normal to the invariant-plane and z_1 is parallel to the shear direction. (Z P Z) is the deformation matrix describing the strain.

Consider a tensile test on a sample which is fully austenitic and polycrystalline. An applied stress can stimulate martensitic transformation, but there are 24 possible crystallographic variants of martensite that can form. A tensile stress has a maximum interaction with the shape deformation when the tensile axis **u**, habit plane normal $\mathbf{z}_3$ and shear direction $\mathbf{z}_1$ lie in the same plane and when the axis is at an angle θ to the plate normal such that $\tan\{2\theta\} = s/\delta$.[6] With $s=0.26$ and $\delta=0.03$, $\theta=42°$; it follows that the tensile axis, represented as a unit vector with respect to the basis Z, is given by

$$[\mathrm{Z};\mathbf{u}] = [\sin\theta \ \ 0 \ \ \cos\theta]$$

$$[\mathrm{Z};\mathbf{v}] = (\mathrm{Z\ P\ Z})[\mathrm{Z};\mathbf{u}]$$

so that

$$[\mathrm{Z};\mathbf{v}] = [(\sin\theta + s\cos\theta) \ \ 0 \ \ (1+\delta)\cos\theta]$$

In a tensile test the effect of constraint due to the grips is to cause the sample to rotate [*e.g.* Ref. 5)] making $\mathbf{v} \parallel \mathbf{u}$ so that the net strain along the tensile axis is given by

$$1 - |\mathbf{v}|/|\mathbf{u}| = 0.15$$

This means that when an austenitic tensile test specimen transforms completely into martensite, the maximum tensile elongation due to phase transformation is about 15%. However, the TRIP-assisted steels which are the subject of this paper typically contain 5–15% retained austenite. Therefore the contribution to elongation from transformation plasticity is the calculated level for a fully austenitic sample multiplied by the volume fraction of austenite,[7] *i.e.* in the range 0.75–2.25%. This assumes the formation of the most favoured variant and complete transformation into that variant. If the variants form at random then the total strain must be even smaller; the shear strains cancel completely in the limit of random transformation.

3. Summary

TRIP-assisted steels of the type discussed here typically exhibit uniform tensile strains of about 15–30%; of this, only about 2% may be a consequence of transformation plasticity. It is possible that the role of TRIP has been exaggerated in explaining the good mechanical properties of these steels.

The hard phase (martensite or bainite) in a dual phase steels has a large strain hardening coefficient, high strength and low ductility. By contrast, the soft phase (ferrite) has a low strain hardening coefficient (n), low strength (σ_Y) and high ductility (ε_U). When the composite microstructure is stressed, the plastic strain is at first focussed in the more ductile soft phase, which work-hardens.[8,9] Eventually, the harder phase also deforms plastically. It has already been shown[9] that this composite deformation behaviour leads to intermediate combinations of n, σ_Y, ε_U. The dual phase microstructure thus exploits the high strength and n values of the hard phase, and the high ductility of the soft phase. The fact that the plastic strain is at first focussed in the soft phase is advantageous since the hard phase can reserve its ductility until the later stages of overall deformation.

It is likely that the good uniform elongation properties of TRIP-assisted steels are due to the composite deformation behaviour of the major phases with the retained austenite playing a minor role.

This conclusion is consistent with recent work by Jacques *et al.*[10] who argue that although low-silicon steels contain only a small amount of retained austenite, the composite effect gives uniform elongation which is superior compared with many commercial steels currently used in the manufacture of automobiles.

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REFERENCES

1) O. Matsumura, Y. Sakuma and H. Takechi: *Trans. Iron Steel Inst. Jpn.*, **27** (1987), 570.
2) H. K. D. H. Bhadeshia: Bainite in Steels, 2nd Ed., Institute of Materials, London, (2001), 343.
3) Anonymous, *Materials World*, **10** (2002), 22.
4) J. S. Bowles and J. K. MacKenzie: *Acta Metall.*, **2** (1954), 129.
5) H. K. D. H. Bhadeshia: Geometry of Crystals, Institute of Materials, London, (1987).
6) J. R. Patel and M. Cohen: *Acta Metall.*, **1** (1953), 531.
7) J. W. Christian: *Metall. Trans. A.*, **13A** (1982), 509.
8) Y. Tomota, K. Kuroki, T. Mori and I. Tamura: *Mater. Sci. Eng.*, **24** (1976), 85.
9) H. K. D. H. Bhadeshia and D. V. Edmonds: *Met. Sci.*, **14** (1980), 41.
10) P. Jacques, E. Girault, Ph. Harlet and F. Delannay: *ISIJ Int.*, **41** (2001), 1061.