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DEFORMATION BEHAVIOUR OF Ti-50.3 AT %Ni ALLOY

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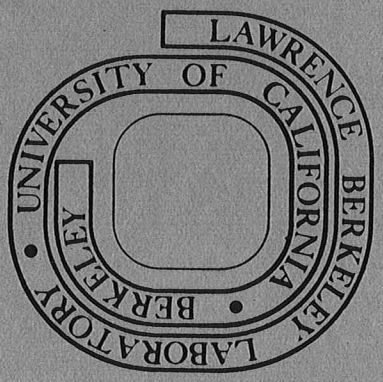

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DEFORMATION BEHAVIOUR OF Ti-50.3 at %Ni ALLOY

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ABSTRACT

The early stage deformation behaviour of Ti-50.3 at %Ni alloy has been investigated. It was found that stress induced (i) twin-boundary migration within existing martensite variants, (ii) migration of twin boundaries between twin-related adjacent martensite variants, (iii) re-orientation of existing martensite by twinning on the most favorably oriented twin system and (iv)additional transformation at the expense of retained high temperature phase.

INTRODUCTION

The alloy NiTi near the equiatomic composition has been known to undergo a reversible martensitic-type phase transformation in the vicinity of room temperature. Associated with this transformation is a "mechanical shape memory effect". The memory is such that if a specimen is deformed below the Ms temperature (martensite start temperature during cooling) and then heated, it tends to recover its original undeformed shape. The purpose of this paper is to report the operative deformation modes in the early stages which are thought to give rise to the fully recoverable strain. For detailed discussions of shape memory alloys, the reader may consult reference (1).

EXPERIMENTAL PROCEDURE

All the specimens (sheets 1 mm thick) were solution treated at 1000°C for 24 hours in quartz capsules (argon atmosphere, ~10^{-6} torr) and then quenched in ice water. Chemical analysis done after such treatment showed the oxygen content to be ~350 ppm and the nitrogen content <10 ppm. The Ms temperature as determined from the peak of the electrical resistivity vs. temperature diagram (2) was found to be ~55°C. At room temperature the material was partially transformed into martensite (the average volume fraction of martensite was ~70% as estimated from optical micrographs). Thin foils for transmission microscopy were prepared by the jet polishing technique in a solutuion containing 1 HNO_3:3 Methanol by volume. The foils were examined in a Siemens IAEM and Philips 100 EM equippedwith a deformation holder. The specimens were glued to the holder using Eastman #910 adhesive. All the micrographs were taken at room temperature at an operating voltage of 100kV.

EXPERIMENTAL RESULTS AND DISCUSSION

The martensitic phase was found to form mostly in self-accomodating groups. Figure (1) is a bright-field image showing a zig-zag arrangement of martensite plates. Selected-area diffraction and dark-field imaging verified that the parallel bands within each member of the group shown in fig. (1) are twin-related along {111} plane of the martensite structure (distorted orthorhombic). The twin shear direction was determined from the geometry of the martensite structure and the formula given by Andrews and Johonson(3). This was found to be close to <123>. Members of a self-accomodating group of martensite plates are themselves twin-related along {111} as has been verified by trace

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analysis of electron micrographs and their corresponding diffraction patterns. These observations suggest that stress-induced twin boundary migration may play an important role in the early stages of deformation. Since twinning was observed to occur on a fine scale, this deformation mode could not be examined optically as in the case of In-Tl (4), Au-Cd (5) and Cu-Al-Ni (6) alloys. Figure (2a) is a bright-field image of a twinned martensite plate. Figure (2b) shows the same area of (a) imaged under the same diffraction conditions after the foil had been slightly bent outside the microscope at room temperature. The image of (b) was printed to be the mirror image of (a) and then both images were cut along the same line.

By comparing the two micrographs it can be seen that one of the two sets of twin-related domains has grown at the expense of the other. This shows that the twin-boundaries within a martensite plate are mobile. Figure (3) shows an example of an "in situ" deformation experiment. It can be seen that after deformation in tension, the martensite variant marked "A" has grown at the expense of "B" which suggests that the twin boundaries between martensite variants which belong to a self-accomodating group are also mobile. In addition, fine parallel bands have appeared at C which are probably twins within a martensite variant which was outside the field of view and has grown under stress. During the course of "in situ" deformation experiments it was sometimes observed that sets of twins within a martensite variant have disappeared and been replaced by another set running in a different direction. Figure (4) shows an example. It can be seen that in addition to the widening of the twins at "A" after deformation, that the set at "B"

have disappeared and been replaced by another set running parallel to "A". This can also be seen at "C". It is proposed that for those sets of twins whose {111} <123> twin shear does not interact favorably with the applied stress may be replaced by another set whose twin shear does interact favorably. This may provide a mechanism for re-orientation of the martensite without transforming first to the high temperature phase as has been hypothesized by Wasilewski (7). The ease with which twin boundaries migrate under stress may be determined in part by the magnitude of the twin shear (8). In the present case this is 0.245 and the Burgers vector of the twin dislocation is 0.5Å. The relatively small value of this shear may explain the low-stress levels at which twin-boundaries were observed to migrate. Figure (5) shows a typical true tensile stress-strain diagram at room temperature. The maximum recoverable strain corresponds to point "C" and the observed deformation modes would be operative within stage BC which is characterized by a relatively low strain hardening rate. The observed deformation modes in the early stages were further confirmed by an interesting observation. It was found that if a specimen was bent at room temperature and then further cooled it continued to bend spontaneously in the same direction. This is believed to be related to the observed deformation modes in the following way. Since further cooling causes the martensite plates to grow, after bending those sets which have been already preferentially developed by the initial bending would make the major contribution to the new thermally transformed volume. This would contribute to the observed macroscopic strain. Also further growth of martensite plates, in which one set of twins had been widened at the expense of the other and those

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which have been reoriented and grown at the expense of other plates would contribute to additional macroscopic strain. It is suggested that the sum of these strains is the cause of the observed spontaneous strain.

Since all the observed deformation modes are related to the reversible transformation process, it would be expected that the strain associated with these modes would be reversed when the martensite reverts to the high temperature phase.

ACKNOWLEDGEMENTS

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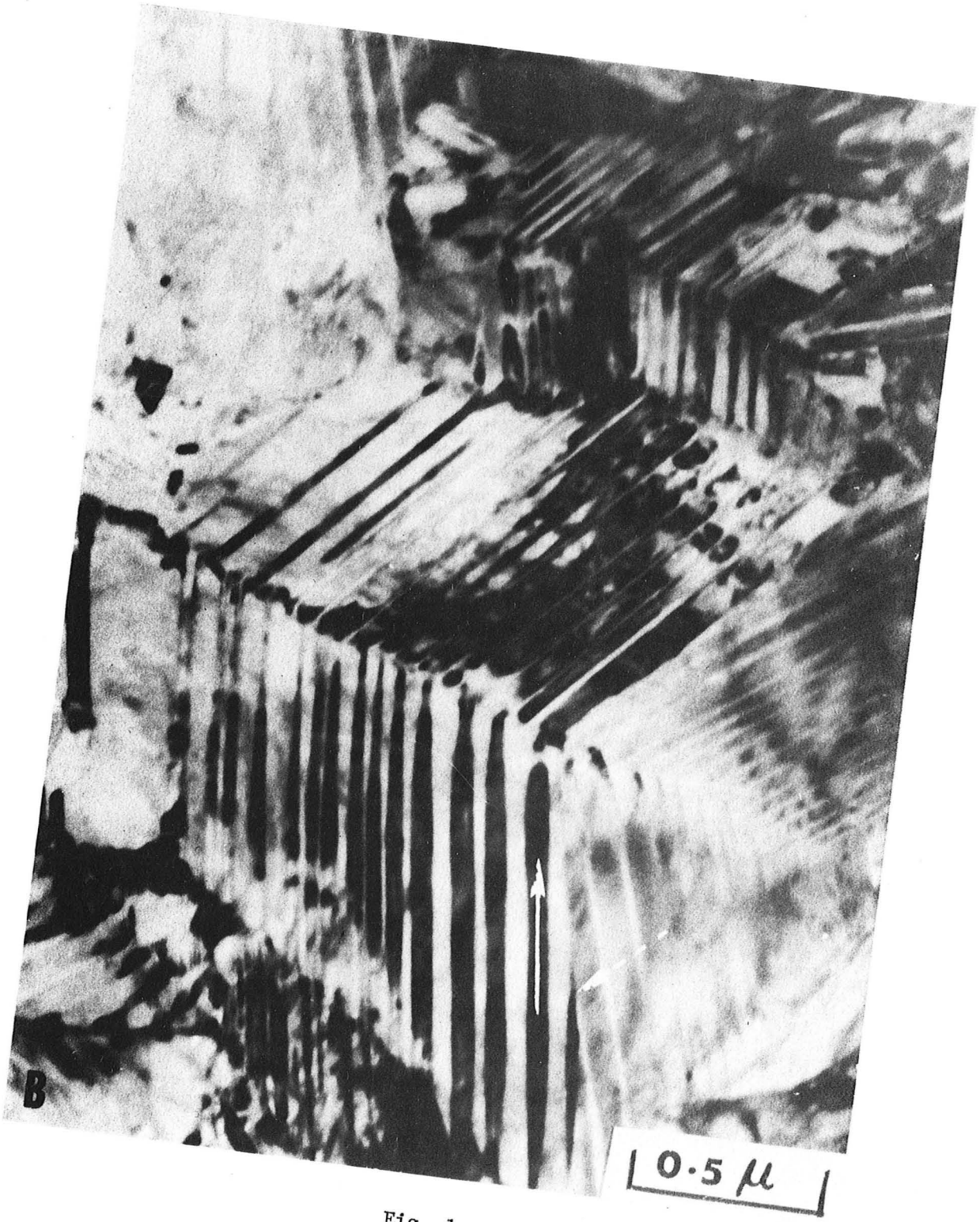

Fig. 1

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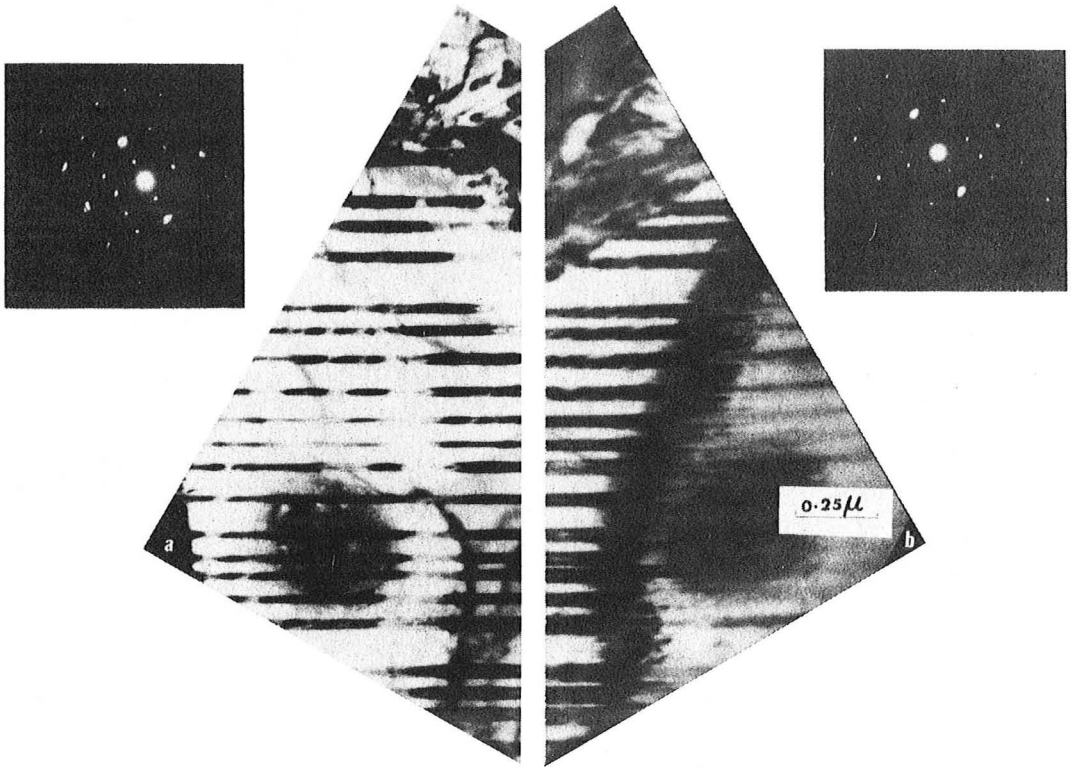

Fig. 2 XBB 765-3846

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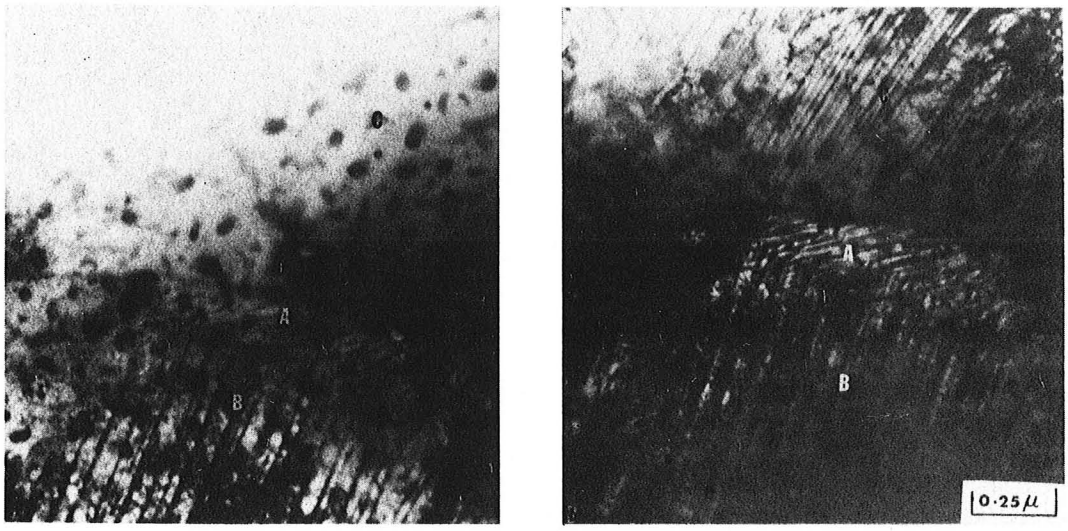

Fig. 3 XBB 765-3847

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Fig. 4

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