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STRUCTURE OF STRAIN-INDUCED MARTENSITE AND CRYSTALLOGRAPHY OF TWINNING IN Ti-62 % Ta ALLOY

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ABSTRACT

The martensites produced by plastic deformation in the austenite structure of Ti-62 % Ta alloys are needle-like martensites and are called as strain-induced martensites. These deformation products are formed in the configuration of parallel lines in austenite matrix and contain crystallographic properties similar to those of other Ti-Ta alloys. These martensites have been to a certain crystallographic direction in the parent phase which is $[\bar{1}01]_a$ of the austenite crystal structure. The crystallographic direction of twinnings, which produced in austenitic region and advanced in martensite by the effect of plastic deformation, was found as $[0\bar{1}0]_a$ and $[\bar{1}\bar{1}20]_m$ relatively in the parent and product phases. The crystal structures of the phases were determined as body-centered cubic (bcc) and hexagonal close-packed (hcp). In addition to the deformation tiwinnings mentioned above, the twinnings which created in two other directions have also been observed and their crystallographic directions were found as $[10\bar{1}1]_m$ and $[\bar{1}101]_m$ in the product, and $[\bar{1}10]_a$ and $[\bar{1}\bar{1}2]_a$ in the parent phases.

INTRODUCTION

Martensitic transformations in Ti-Ta alloys have been examined by other authors in the alloys with tantalium ratios changing between 5.8 % – 53 %, and seen that martensitic properties had changed dependly upon tantalium ratio as shown by Bywater and Christian (1972). Martensite crystals of Ti-Ta alloys with tantalium percentage less than 22 % have hexagonal close-packed (hcp) structure while between 22 % and 53 %, it is orthorombic.

Although it was mentioned in early studies that the martensite crystals in the alloys with tantalium ratio less than 32 % are twinned

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on the $\{\bar{1}101\}_{\alpha'}$ or $\{\bar{1}11\}_{\alpha''}$ planes and are not twinned in the ratio used in this study, recent electron microscope and electron diffraction studies made on Ti-62 % Ta alloys showed that this alloy martensites are also twinned in definite crystallographic directions.

Tantalium in Ti-Ta alloys plays the role of light austenite stabilizier and at the room temperature there are widely and steadly $(\alpha + \beta)$ phase fields, where α and β are martensitic and austenitic phases, relatively. The starting temperature of martensite production, M_s, is higher than the room temperature and this temperature decreases against increasing tantalium ration as mentioned earlier by Dewez (1954).

Despite the previous studies reporting that martensite crystals produced in the austenite matrix of various alloys give rise to production of new martensites by the autocatalysis effect (Nishiyama, 1978), similar effects in the bulk structures have not been seen. In addition to the observed twinnings caused by the distortions produced in martensite crystals, it was also found in Ti-62 % Ta alloy that some additional twinnings were created in the austenite matrix and advanced in the martensite crystals.

These results indicate that lattice imperfections in the bulk structure, such as twinnings, in austenite matrix during martensite production may directly affect transformation.

MATERIAL AND METHOD

The specimens of Ti-62 % Ta alloy examined in this study were produced as plates which have 2x20x50 mm dimensions and mass of 25 gr by the Royal Aircraft Establishment in England. From these specimens, the discs in 3 mm diameter and 250 μm thickness were prepared by spark-cutter for transmission electron microscope; these discs were processed with HCl acid jet under optic microscope, and very small holes in the middle of them were opened. Martensitic transformation was realized by cooling in ice-water bath after annealing at 830 °C temperature for 3 hours. Some of these specimens were deformed 1 % and 2 % plastically to form strain-induced martensites.

The specimens of Ti-62 % Ta alloy prepared for transmission electron microscope were examined by the electron microscopes at 75 kV, 100 kV and 125 kV acceleration potantials, and it was observed that martensites were created on definite regions of the specimens. The bright field micrographs of these martensites were obtained and examined in conjuction with the electron diffraction patterns obtained from the same fields.

EXPERIMENTAL RESULTS

1. Strain-Induced Martensites

Martensitic transformations in various metals and alloys can be produced both by decreasing the matrix temperature below the starting point of martensite, M_s, and plastically deforming its crystal structure.

Generally, there is no clear midrib in Ti-Ta martensites, as observed in various alloys by Nishiyama (1978). The martensites created by thermal and strain effects are in shape of needles. Such martensites produced by the strain effect in Ti-62 % Ta alloy are seen in Figure 1. Electron diffraction pattern obtained from the austenitic region is also shown in Figure 2a. The crystal structure of parent austenite phase in Ti-62 % Ta alloy was determined as body-centered cubic and the key diagram of this electron diffraction pattern is given in Figure 2b.

The martensite direction in Figure 1 was utilized together with the key diagram revealed that the strain-induced martensites are formed on $[\bar{1}01]_a$ direction inside austenite crystal.

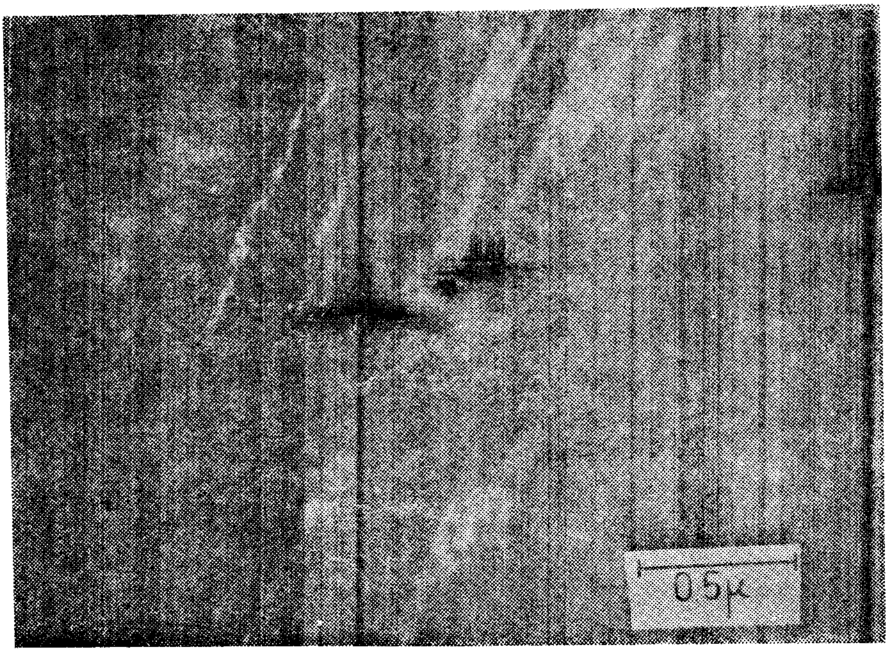


FIGURE 1. Strain-induced martensites in Ti-62 % Ta alloy.

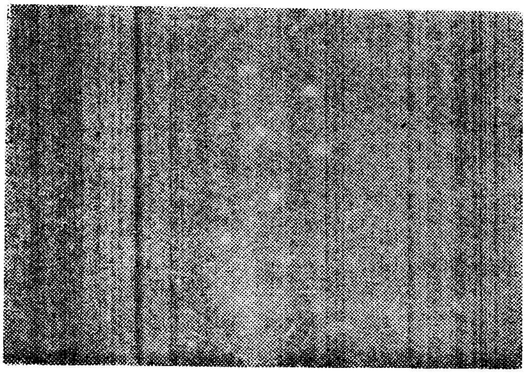


FIGURE 2. (a) Electron diffraction pattern taken from austenitic region

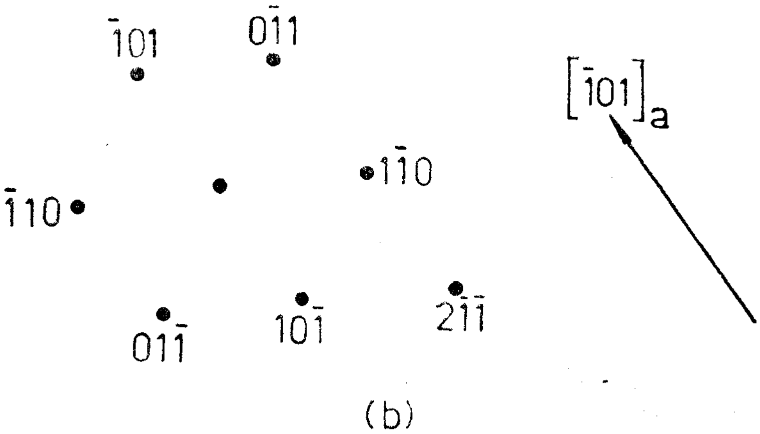


FIGURE 2. (b) Indexed key diagram of this pattern and crystallographic direction of martensites.

2. Double Twinnings in the Martensite Structure

As the martensitic transformations are formed in the bulk structures of Ti-62 % Ta alloys, they are accompanied by the lattice imperfections. The twinnings are these types of structures created by the various effects. As a result of these formations different volumes are created in such a manner that they are symmetrical relations with in other.

In the first crystallographic martensite theories developed by Wechsler, Lieberman and Read (1953) and Bowles and Mackenzie (1954), it was accepted that the number of invariant plane strains is only one. In the result of observations made later in iron base alloys, it was found that the number can be more than one. These were the reasons for the development of double shear martensite theories by Acton and Bevis (1969) and Ross and Crocker (1970). The martensitic transformations with $\{225\}$ habit planes were better explained by these new theories. Recently, it was also shown by Durlu (1978) that three different systems of lattice invariant structures can be existed in some Fe-Ni-C alloy martensites with $\{259\}_f$ habits.

In the earlier studies on martensitic transformations in Ti-Ta alloys it was observed that martensite crystals in the alloys with tantalium ratio less than 32 % were twinned on $\{\bar{1}101\}_{\alpha'}$ or $\{\bar{1}11\}_{\alpha''}$ planes, while above this limit they are not twinned at all (Bywater and Christian, 1972).

In the present study, it was seen that two kinds of twinnings of different directions have appeared in product phase crystals formed in Ti-62 % Ta alloy austenites, as shown in Figure 3. Electron diffraction pattern taken from the same martensitic region, on which twinnings have created, is also seen in Figure 4a. The indexed reciprocal lattice points of parent and product phases are shown together.

The reciprocal lattice points corresponding to both phases in the diffraction pattern were indexed seperately and illustrated on the in-

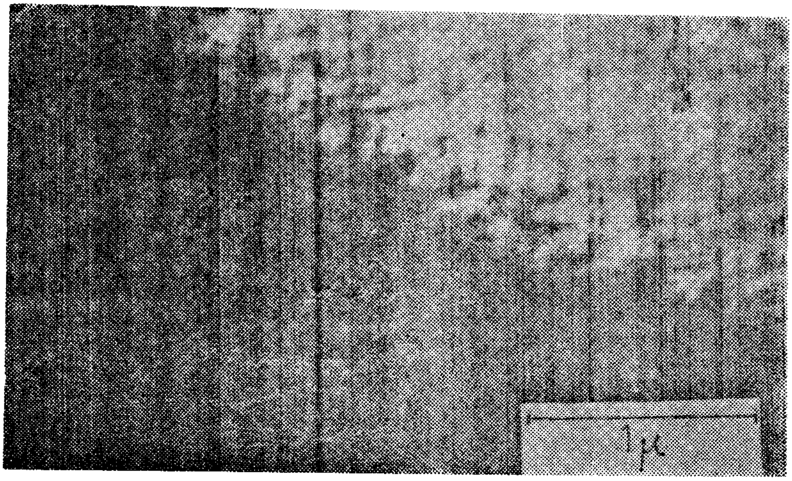


FIGURE 3. Double twins on the martensite in Ti-62 % Ta alloy.

dexed key diagram in Figure 4b and 4c. The direction of these twinnings in Figure 4a were carried to the key diagram and it was found that these directions were $[10\bar{1}\bar{1}]_m$ and $[1\bar{1}01]_m$ of product martensite crystal structure, and $[\bar{1}10]_a$ and $[\bar{1}\bar{1}2]_a$ of parent austenite phase.

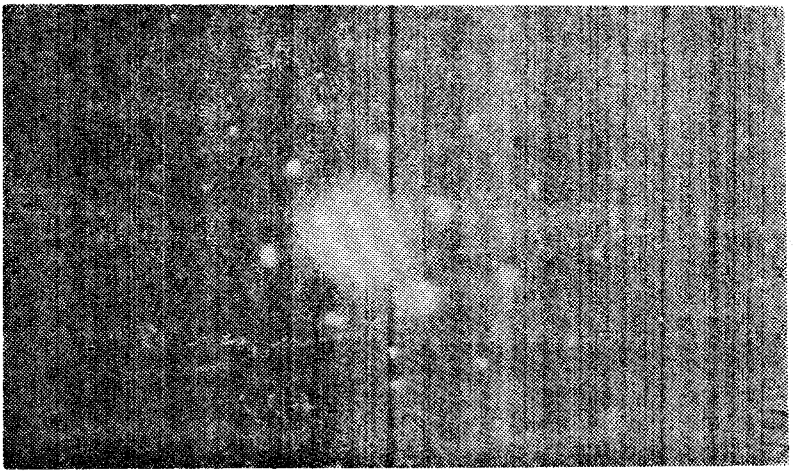
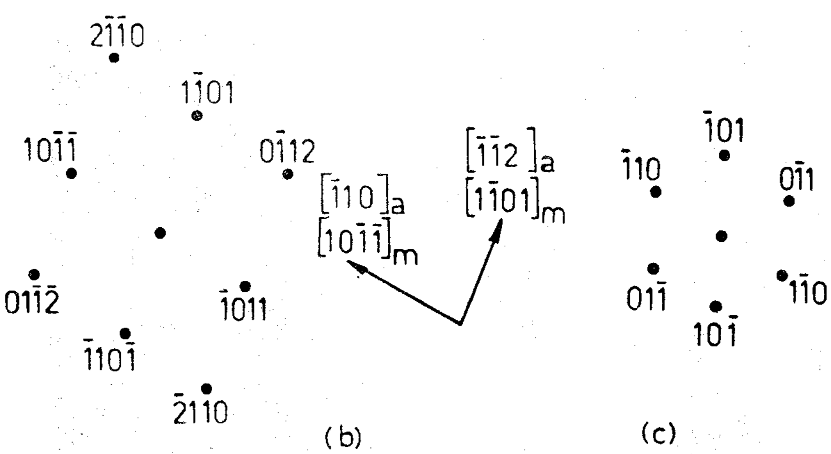


FIGURE 4. (a) Electron diffraction pattern taken from austenite-martensite interface,



(b), (c) indexed key diagrams of martensite and austenite difractions and twinning directions.

3. Twinning of Parent Structure

In addition to the twins created in the martensite phase crystals in Ti-62 % Ta alloy, it was observed that some twins are formed in the matrix austenite and continued in the product martensite phase. This phenomena indicates that the twins created in any phase region not only remain in the parent phase crystal but also can advance in the product phase regions.

The formation of martensite phase by the transformation in the austenite matrix has been caused by some crystal structure defects (Bilby and Christian, 1961). Any lattice imperfection observed in the parent phase can advance in the product phase also, and this shows that any distortion created in austenite phase region gives rise to a new distortion in the product martensite phase. An example of such twins in Ti-62 % Ta alloy is shown in Figure 5, and corresponding electron diffraction pattern taken from the same area is given iin Figure 6a. Reciprocal lattice points of the electron diffraction pattern corresponding to martensite and austenite phases are shown in Figure 6b and 6c, respectively. These twins seen in Figure 5 are formed in the definite directions in austenite matrix and martensite product. The brightfield

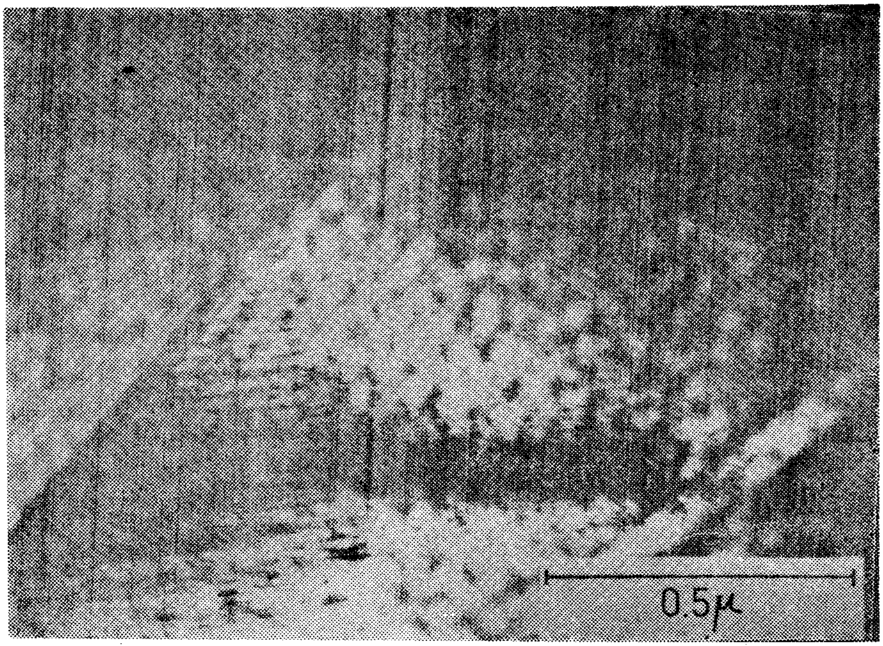


FIGURE 5. The twins produced in Ti-62 % Ta alloy.

micrograph was utilized in conjunction with corresponding diffraction pattern, and it was found that these twins are formed in $[0\bar{1}0]_a$ and $[\bar{1}\bar{1}20]_m$ directions of austenite and martensite crystals, respectively. On the other hand, the twins created on $[0\bar{1}0]_a$ direction of austenite matrix is advanced on $[\bar{1}\bar{1}20]_m$ direction of martensite structure. This

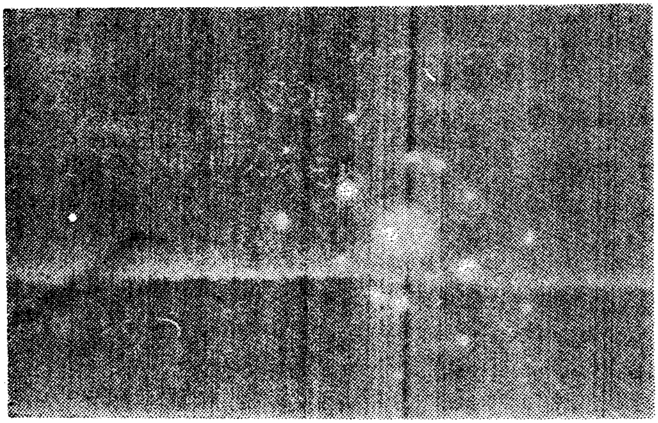
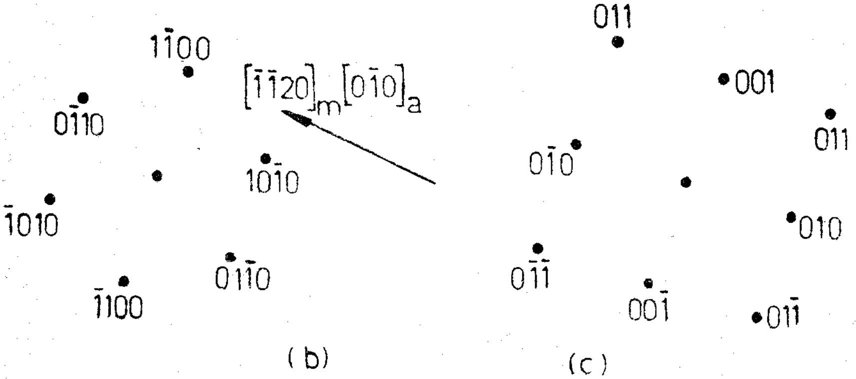


FIGURE 6. (a) Electron diffraction pattern obtained from austenite martensite interface;



(b), (c) Indexed key diagrams of electron diffraction patterns corresponding to martensite and austenite phases, and directions of twins.

result indicates that any lattice imperfection formed either in parent or product phases can affect the other structure and ones its formed can easily be advanced in the other structure.

It was stated earlier by Nishiyama (1978) that the martensite crystals formed in the austenitic regions of various alloys can cause the formation of the new martensites in a autocatalitic way, but similar effects have not been observed in the bulk type lattice imperfections yet. These results indicate that these types of imperfections, such as twins, can also play an important role in the formation.

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