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SHOCK INDUCED MARTENSITIC TRANSFORMATIONS IN BCC Fe-Mn

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1. Introduction

Recent experiments have shown that BCC α-iron transforms to a close-packed phase under shock pressures[1,2]. The effect of dynamic pressure produced by intense shock waves on the pressure volume relations was first studied by Bancroft, Peterson and Minshall[3]. The nature of the high pressure phase which must form and revert in the order of 10^{-6} seconds has not been established. Static experiments however, have shown that in pure iron, at room temperature, the high pressure phase is hexagonal close packed ε [4,5].

The addition of alloying elements to iron modifies the temperature pressure diagram, and the stability of the γ or ε fields can be increased by the addition of manganese. Consequently, the shock loading of the Fe-Mn alloys which have been subzero quenched to form α-martensite (α'), results in a pressure induced $\alpha' \rightarrow \gamma$ transformation for the Fe-7.37 wt % Mn alloy and $\alpha' \rightarrow \varepsilon$ for the Fe-14 wt % Mn alloy. It is the object of this paper to report the morphology and crystallographic features of the α' to γ and α' to ε transformations.

2. Experimental Methods and Results

The Fe-Mn alloys were austenized for five hours at 950°C and then quenched to 77°K. This subzero quench produced 86% α-martensite in the alloys. Foil specimens of the alloys, 3 cm by 3 cm were shock loaded to peak pressures of 90, 150 and 300 kb using the driver plate technique[6]. Thin foils suitable for transmission electron microscopy were prepared from

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materials before and after shock loading. Surface trace analysis was used to find the habit planes of the transformed regions, and orientation relations were determined by electron diffraction.

The Fe-7.37 Mn specimens shock loaded to 90 kb had plates of γ transformed from α-martensite. Tilting of the specimen showed that the γ bands were not remnants of the martensite. The γ plates were surrounded by deformation twins in the martensite and were associated with screw dislocations lying on the $\{110\}_M$. At 150 kb, the plates observed were internally twinned on {111} planes, and it is believed that the internal twins are associated with an inhomogeneous shear in the $\alpha' \to \gamma$ transformation. These internal twins were similar to those observed by Bowden and Kelly (8) in Fe-Ni. At 300 kb, extensive transformation occurred.

Single surface analysis was employed to determine the habit plane for a particular variant of the orientation relationship. The angle between the habit plane and the foil normal was calculated using the foil thickness values (2500 A°) and the projected width of the α habit plane interface. In this way, the position of the habit plane normal on the great circle was determined via single surface trace analysis.

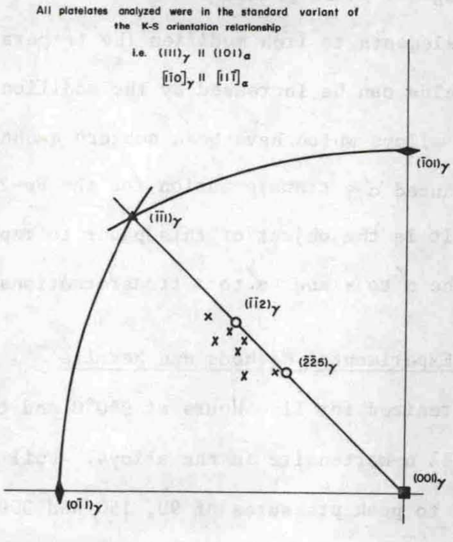

FIG I

Stereographic projection of habit planes observed at 90 kb.

From Figure 1, two different types of habit planes were observed at 90 kb. Five habits were approximately $(\bar{1}\bar{1}2)_\gamma$, and only one was near the $(\bar{2}\bar{2}5)_\gamma$. At 150 kb., for the variant of the orientation relationship used, the habit plane was always found to be near to $(\bar{1}\bar{1}2)_\gamma$.

The position of the habit plane depends on the choice of inhomogeneous shear system and the values of the lattice parameters. The inhomogeneous shear system whose habit plane is the $(\bar{1}\bar{1}2)\gamma$ has been found to be the $(111)_\gamma[\bar{1}2\bar{1}]_\gamma$, while the shear system of the habit plane $(\bar{2}\bar{2}5)_\gamma$ is the $(110)_\gamma[1\bar{1}0]_\gamma$. The set of traces analyzed failed to define a specific habit plane. This scatter may be due to the poorly resolved γ plates. A real variation due to varying lattice parameters however, cannot be ruled out. In determining the dilation parameter δ, we note that the $(111)\gamma[\bar{1}2\bar{1}]_\gamma$ traces tended to be closer to zero dilation which is necessary for a transformation induced by a compressive shock front.

The shear system of the $(\bar{1}\bar{1}2)_\gamma$ habit involves a shear on the $(101)_\alpha$ which is 80° from the habit plane of zero dilation. The γ plates observed at 90 kb were internally twinned on the $\{111\}_\gamma$. The $\{111\}_\gamma$ twinning plane was always found to be at an angle of 80-90° to the habit plane. We conclude that the internal twins are not deformation twins but are a result of the inhomogeneous shear in the α' to γ transformation. The internal twins further indicate that the transformation occurred through a shear system of the type $(111)_\gamma[\bar{1}2\bar{1}]_\gamma$.

The untransformed α-martensite showed the typical structure of cold worked metals. On transforming, no preferrential nucleation sites were observed. Since γ bands were found with deformation twins, it is believed that there is some relationship between the nucleation of twins and γ plates.

In the Fe-14 Mn alloy, single α' plates as opposed to a twin related pair were observed in specimens shock loaded at 90 and 150 kb. These single plates may be due to the $\alpha \to \varepsilon \to \alpha'$ transformation. In explaining these observations one must consider the orientation relationships between γ, ε and α. The orientation relationship is[9,10]

$$(111)_\gamma \;||\; (0001)_\varepsilon \;||\; (101)_\alpha$$
$$[110]_\gamma \;||\; [1210]_\varepsilon \;||\; [111]_\alpha$$

with the standard viriant of the KS relationship. The convention of BCC α to HCP ε requires an invariant plane strain on $\{112\}_\alpha$ together with a dilation (δ) of about 1.5%. The dilation is in the form of a small uniform expansion[11]. However, under a compressive shock wave, the dilation is not energetically favorable, and any transformation that does take place must have $\delta \sim o$. In terms of microscopy, the α plates are single plates, since as δ approaches zero from its maximum value, the habit planes for a twin related pair diverge.

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