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THE INFLUENCE OF HYDROSTATIC AND SHOCK PRESSURE ON THE BCC \rightarrow (HCP, FCC) TRANSFORMATION IN Fe-Mn ALLOYS

by

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1. Introduction

The pressure-induced phase transformations in iron-rich Fe-Mn alloys have been studied by the shock technique (1-3) and by the hydrostatic pressure technique (4). Christou and Brown (2) have found that the addition of manganese to iron decreases the shock transition pressure from 133 kbar for pure iron to less than 70 kbar for Fe-14 wt% Mn. For alloys up to 7 wt%, the FCC phase is stabilized, while the ϵ (HCP) phase is stabilized for the Fe-14 wt% Mn alloy. Saturation magnetization studies have detected a reduction in magnetization due to the high pressure phase.

Biles and Marder⁽⁴⁾ have studied the hydrostatic pressure induced transformation in Fe-Mn and have showed that for Fe-4.9 wt% Mn, Fe-9.6 wt% Mn and Fe-13.9 wt% Mn, the effect of manganese is to promote the formation of the HCP phase. In addition, in the case of Fe-13.9 wt% Mn and Fe-17.7 wt% Mn alloys, none of the HCP transformed back to BCC as the pressure was released. It is of interest to compare the two pressure-induced transformations (shock and hydrostatic pressure) and to explain the difference in the high pressure crystal structure of the two transformations.

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2. The Shock-Induced Transformation

It has been shown⁽²⁾ that the addition of manganese to iron has modified the temperaturepressure diagram by increasing the field of stability of the FCC and HCP phase. Therefore, the shock loading of a BCC-martensite structure with an appropriate solute content results in an $\alpha + \gamma$ or $\alpha + \varepsilon$ transformation. Figures 1 and 2 show that the triple point has been lowered to about 90 kbar for Fe-7 wt% Mn and 70 kbar for Fe-14 wt% Mn, thereby stabilizing the FCC and HCP fields with respect to the BCC phase. The T₀-P (equilibrium temperature-pressure) lines for the Fe-7 wt% Mn and Fe-14 wt% Mn alloys as a first approximation were drawn parallel to the phase lines for pure iron, and were also made to pass through the two experimentally known states (T₀, P=0 and T_c, P_c). The temperature T_c is the temperature of the compressed solid at P_c, the transformation pressure, calculated using the equations of McQueen et al⁽⁵⁾. The calculation of the initial T₀-P slope (P=0, T=T₀) for Fe-7 wt% Mn and Fe-14 wt% Mn is based on the Clasius-Clapyron equation. The initial PT slope for the $\alpha + \gamma$ transformation has the following values:

$$\left(\frac{dT}{dP}\right)^{\alpha \to \gamma} = -10.5$$
 °K/kbar

The enthalpy change $\Delta H_{\alpha \rightarrow \gamma}$ and the entropy change $\Delta S_{\alpha \rightarrow \gamma}$ are functions of temperature and solute concentration. Therefore, the slope of the T₀-P curve will deviate from the slope of the pure iron phase lines.

On the temperature-pressure diagrams of Figures 1 and 2 we may superimpose the Fe-Mn $T_{\rm H}$ -P states, where $T_{\rm H}$ is the temperature rise induced in Fe-7 wt% Mn and Fe-14 wt% Mn by the passage of a shock wave. To calculate $T_{\rm H}$ we must take into account the Rankine-Hugoniot equations, ⁽⁶⁾

$$E_{\rm H} - E_{\rm o} = 1/2 P_{\rm H} (V_{\rm o} - V)$$

where E is the total energy of the Fe-Mn alloy per unit mass. The internal energy may be approximated by the equation,

 $E \simeq u(V) + 3 NkT$

In equation (2) u(V) is the ground state energy of the solid, T is the temperature, V is the volume, k is Boltzman constant and N is the number of atoms per gram. It can be shown⁽⁶⁾ that:

$$u(\nabla) = \phi(\nabla) + \left(\frac{\nabla}{\nabla}\right)^{\gamma} \sum \frac{1}{2h\nu}$$

$$i \quad i$$

(1)

(2)

(3)

where $\phi(V)$ is the cohesive energy, $\gamma = 1.6$, and ν are the phonon frequencies. Equations (1) and (2) may be combined in order to obtain the expression for T_u:

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FIGURE 1 Temperature-Pressure Diagram for Fe-7Mn



FIGURE 2 Temperature-Pressure Diagram for Fe-14Mn

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$$T_{\rm H} - T_{\rm o} = \frac{C}{3Nk} \left[\frac{P}{2\rho_{\rm o}} \left(1 - \frac{V}{V_{\rm o}} \right) - \left(u(V) - u(V_{\rm o}) \right) \right]$$
(4)

where $\rho_0 = 7.87 \text{ g/cm}^3$, $T_0 = 300 ^{\circ}$ K. Table I gives the estimated temperature rise in shocked Fe-7 wt% Mn and Fe-14 wt% Mn.

TABLE I

THE EFFECT OF MANGANESE ON THE PEAK TEMPERATURE

Alloy	Shock Pressure (kbars)	Peak Temperature (T _H) (°C)
Fe-7 wt% Mn	90	150
	150	625
	300	836
	500	1227
Fe-14 wt% Mn	90	430
	150	575
	300	738
	500	1000

The net result of a shock followed by a rarefaction wave is an increase in temperature and internal energy.

As shown in Table I, the peak temperatures attained by the Fe-7 wt% Mn alloy are sufficiently high to result in an $\alpha \rightarrow \gamma$ transformation since the $T_{\rm H}$, P states for this alloy are within the γ field (Figure 1). The peak temperatures attained by the Fe-14 wt% Mn alloy are sufficiently low so that the $T_{\rm H}$, P states for this alloy are entirely within the ε field.

3. Static Experiments at 300°K

The hydrostatic method of applying high pressures is not accompanied by the shock heating effects that are present during shock deformation. The static pressure transformations are therefore abaric. ⁽⁴⁾ From Figures 1 and 2, the effect of pressurization at constant temperature (300°K) will result in an $\alpha \neq \varepsilon$ transformation for the iron rich iron manganese alloys. This conclusion has been verified by reference (4). Therefore, shock heating which accompanies dynamic pressurization of Fe-Mn and is not present during the static experiments, results in a BCC to FCC transformation and not a BCC to HCP.

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