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THE INFLUENCE OF HYDROSTATIC AND SHOCK PRESSURE ON THE BCC → (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.

2. The Shock-Induced Transformation

It has been shown[2] that the addition of manganese to iron has modified the temperature-pressure 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 $\alpha \rightarrow \gamma$ or $\alpha \rightarrow \varepsilon$ 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 T_o-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 (T_o, 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 T_o-P slope (P=0, $T=T_o$) for Fe-7 wt% Mn and Fe-14 wt% Mn is based on the Clasius-Clapyron equation. The initial PT slope for the $\alpha \rightarrow \gamma$ transformation has the following values:

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

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 T_o-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_H-P states, where T_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_H we must take into account the Rankine-Hugoniot equations,[6]

$$E_H - E_o = 1/2 \; P_H \; (V_o - V) \tag{1}$$

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

$$E \simeq u(V) + 3 \; NkT \tag{2}$$

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:

$$u(V) = \phi(V) + \left(\frac{V_o}{V}\right)^{\gamma} \sum_i 1/2 h\nu_i \tag{3}$$

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_H: