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SHOCK INDUCED DENSITY CHANGES IN METASTABLE BCC PHASES

A. Christou*

Laboratory for the Research on the Structure of Matter
and School of Metallurgy and Materials Science
University of Pennsylvania
Philadelphia, Pa.

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1 INTRODUCTION

The effect of shock deformation on martensitic transformations in metastable BCC systems was studied in order to determine whether the high pressure phase may be retained after relief. The system chosen for this investigation was BCC Fe-Mn. For the Fe-Mn alloys (0.38, 4.10, 7.37, 14 wt. pct. Mn, .007 wt. pct. C), initial studies[1,2] indicate that at pressures up to 300 kbar, the stability of the denser high temperature FCC phase increases, with a subsequent decrease in the amount of BCC martensite. Consequently, shock loading Fe-Mn alloys which have been subzero quenched to form a metastable martensitic BCC (α') should result in a pressure induced $\alpha'\gamma$ or ε(HCP) transformation, with γ or ε retained on relief.

For purposes of comparison, we have shock loaded another BCC alloy, β-brass (51.2 wt. pct. Zn) which is metastable with regard to deformation. Massalski and Barrett[3] have studied the effect of cold work on the martensitic transformation in β-brass with compositions from 39.7 to 51.5 wt. pct. zinc. They have concluded that β-brass alloys with 37.0 to 42.0 wt. pct. zinc are metastable with regard to cooling and deformation, while β-brass with above 42.0 pct. zinc is metastable with regard to deformation only.

The present work is an investigation of residual density changes that occur in shock loaded BCC alloys. The results are related to shock induced martensitic transformations.

2 EXPERIMENTAL DETAILS

The Fe-Mn specimens were subzero quenched from 900°C which is above the M_s temperature. β-brass was quenched into liquid nitrogen from above the Curie temperature. The shock defor-

*Present address: Materials Science Division, NWL, Dahlgren, Va.

mation was accomplished in the usual manner.[4] The β-brass shocked samples were recovered from a liquid nitrogen bath. The specimens were shock loaded at pressures of 90, 150, and 300 kb. Shock induced density changes were measured using a displacement technique. Density changes of ±0.0002 g/cm^3 were detectable. The specimens were placed in a sealed case to ensure constancy of temperature. Crystal structure and shock induced phase changes were determined by x-ray diffraction of powdered Fe-Mn and β-brass using M_oK_α radiation for Fe-Mn and copper for β-brass.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Density measurements of the shock loaded Fe-Mn specimens clearly indicate that the high pressure phase has been retained in the alloys Fe-4Mn to Fe-14Mn, shock loaded at pressures above 90kb. The maximum density change occurred after shock deformation at 300 kb. The residual density changes are believed to be due to an $\alpha' \rightarrow \gamma$ or $\alpha' \rightarrow \epsilon$ martensitic transformation since, as shown in Table I, the density change was much less in the alloys that were initially furnace cooled prior to shock deformation. X-ray diffraction patterns of the shock deformed alloys were taken and for the Fe-14Mn alloy, three diffraction lines of BCC Fe-Mn, (110), (200), and (211), were observed. At 300 kb, six lines were clearly identified as the HCP, ε phase. The x-ray diffraction results are summarized in Table I.

TABLE I

Density and X-ray Diffraction Data of Shock-Deformed Fe-Mn Alloys

Alloy (quenched initially)		Density Ratio† Quenched	Density Ratio† Furnace Cooled	Principle Phase
Fe-.38 Mn	90 kb	1.0002	1.0001	BCC
	150 kb	1.0002	1.0002	BCC
	300 kb	1.0002	1.0002	BCC
Fe-4 Mn	90 kb	1.0023	1.0002	BCC
	150 kb	1.0097	1.0006	FCC
	300 kb	1.0146	1.0007	FCC
Fe-7 Mn	90 kb	1.0028	1.0003	BCC
	150 kb	1.0218	1.0006	FCC
	300 kb	1.0427	1.0007	FCC
Fe-14 Mn	300 kb	1.0449	1.0009	HCP

† Density ratio = $\frac{\text{Shocked density}}{\text{Unshocked density}}$

It is well known that β-brass orders so rapidly that a water quench cannot freeze in an appreciable amount of disorder. The β-brass investigation showed that an alloy initially furnace cooled from above the critical temperature resulted in a density change of 2.0 x 10^{-4} g/cm^3 at 300 kb, while shock deformation of an alloy quenched from above the critical temperature resulted in density change of 4.0 x 10^{-4} g/cm^3. The density change of the quenched β-brass alloy prior to shock loading was measured after the decay of the Clarebrough internal friction peak.(5) Metallographic examination of shocked β-brass did not reveal any martensite formation. It is therefore possible that the density changes shown in Table II for the furnace cooled specimens are due to the annihilation of microcracks by dislocations of opposite sign to those originally initiating the cracks. Some mechanical disordering was produced by shock deformation at 300 kb, as was made evident by X-ray diffraction measurements. At 300 kb, the superlattice lines showed some broadening with no corresponding change in the broadening of the fundamental lines. X-ray diffraction data (Table II) has led us to the conclusion that the high pressure phase in β-brass was not retained. Any shock-induced martensite that formed must be reversible. Our results agree with the work of Reynolds.(6) We may also speculate that only the disordered β-brass is metastable to deformation. Plastic deformation must therefore initially disorder the alloy and subsequent subzero temperatures trigger the transformation. However, when β brass is recovered to room temperature reversion takes place.

TABLE II

Density Changes and X-Ray Diffraction Results in β-Brass

Heat Treatment	Shock Pressure (kbar)	Density Ratio†	Major Lines
A	90	1.0002	BCC
	150	1.0003	BCC
	300	1.0004	BCC
B	90	1.0003	BCC
	150	1.0003	BCC
	300	1.0005	BCC
C	90	0.9998	BCC
	150	0.9998	BCC
	300	0.998	BCC

† $\text{Density ratio} = \frac{\text{Shocked Density}}{\text{Unshocked Density}}$

Heat treatments prior to shock loading: A = Subzero quench from 500°C, B = Subzero quench from 460°C, C = slow cooled from 500°C.

It is noted that the density changes in shock deformed Fe-Mn are approximately 10^4 times greater than those of β brass.

It is evident that Fe-Mn in a metastable BCC configuration behaves in a different manner from β brass. The temperature-pressure diagram for iron alloys shows a triple point, and the stability of the high pressure phase has been increased by the addition of manganese. Consequently, we have been able to retain the high pressure phase after the occurrence of the well known polymorphic transition which occurs in many iron alloys. In contrast to Fe-Mn, β-brass which was given the same type of heat treatment prior to deformation must depend on room temperature stabilization of thermo-elastic martensite. In conclusion, the experimental findings of this work show that shock deformation of quenched Fe-Mn alloys with composition of 4 wt. pct. Mn to 14 wt. pct. Mn results in a shock induced phase transformation with the high pressure phase retained upon relief.

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