

Stability of the magnetic phase transformation in shocked Fe-Ni alloys

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ABSTRACT

Hugoniot-equation-of-state data recently published by Christou indicated that the addition of nickel to iron increased the pressure required to bring about the shock-induced martensitic phase transformation. The data were said to agree with previous experimental measurements. It was also implied that the increase in transition pressure was in agreement with theory. The purpose of this communication is to point out that Christou's measurements are in disagreement with all previous experimental measurements and theoretical predictions which show that the transition pressure decreases with increasing nickel content.

In a recent paper, Christou (1973) presented data which showed that the pressure required to bring about the shock-induced martensitic transition in iron-nickel alloys increased with increasing nickel content. The measurements indicated that the '130 kbar' transition in pure iron was *increased* to 150 kbar with the addition of 28.6 wt % Ni. The author stated that his data *were in agreement* with previous experimental observations of Fowler, Minshall and Zukas (1961) and also implied that his data *were in agreement* with theoretical predictions.

The purpose of this correspondence is to call attention to the fact that Christou's findings on the Hugoniot behaviour of shock-loaded iron-nickel alloys are in error. We base this conclusion on these observations: (1) Christou's results are in disagreement with all previous experimental measurements on iron-nickel alloys, and (2) his results oppose predictions of *all* previous theoretical investigations of stress-assisted martensitic transformations in iron-nickel alloys. Moreover, Christou's observation that ϵ was retained in shock-loaded Fe-28.6 wt % Ni conflicts with previous results.

The effect of pressure on the transformation of martensitic iron-nickel alloys has been determined by a number of independent investigators by several different methods. Fowler *et al.* (1961) and Loree, Warnes, Zukas and Fowler (1966) used shock-compression techniques to determine that the transition pressures of a series of martensitic iron-nickel alloys were continuously decreased to about 85 kbar at 30 wt % Ni.

Rohde (1970) studied the effect of temperature on the 70 kbar shock-loading transition pressure of a martensitic iron-28.4 at.% nickel-0.5 at.% carbon alloy. Kaufman, Leyenaar and Harvey (1960), Rohde and Graham (1969), and Pope and Edwards (1973) studied the transformation of martensitic iron-nickel and iron-nickel-carbon alloys under hydrostatic pressure and determined the decrease in transition temperature with pressure. The cited shock-loading and hydrostatic pressure experiments all agree in concluding that the pressure of the iron transition is *lowered* by nickel additions. In spite of the fact that Christou cited agreement with the data of Fowler *et al.* (1961), his data are in disagreement with Fowler *et al.* as well as all other measurements.

Theoretical treatments of martensitic transformations in iron and iron-nickel alloys have been presented by Kaufman and Cohen (1956), Kaufman *et al.* (1960), Russell and Winchell (1972), Hillert (1958), Patel and Cohen (1953), and Fisher and Turnbull (1953). These theories, which have a common thermodynamic basis, all predict that the addition of nickel to iron should *lower* the pressure for the transformation of martensite to either the f.c.c. γ phase or the h.c.p. ϵ phase. The theories have been successfully applied by Kaufman *et al.* (1960), Rohde and Graham (1969), Pope and Edwards (1973), Russell and Winchell (1972), Rohde (1970), and Rohde and Albright (1971) to describe experimental measurements of the reversion of martensite to austenite in iron-nickel and iron-nickel-carbon alloys. Thus Christou's measurements are also in disagreement with theoretical predictions on the transformation of martensitic iron-nickel and iron-nickel-carbon alloys which show that the addition of nickel *decreases* the transformation stress.

Leslie, Stevens and Cohen (1964), and Bowden and Kelley (1967) observed residual microstructures of shock-loaded, martensitic iron-nickel and iron-nickel-carbon alloys. They found that for nickel additions above about 28% only γ existed after shock-loading. Neither the study by Leslie *et al.* (1964) nor that by Bowden and Kelly (1967) found any evidence of a retained h.c.p., ϵ phase. These post-shock examinations are in disagreement with Christou's observation that the ϵ phase is retained after shock-loading Fe-28.6 wt % Ni to 300 kbar.

The experimental and theoretical evidence overwhelmingly suggests that Christou's measurements are in error. His findings are contrary to *all* previous investigations of the alloy system. While insufficient experimental details are given in Christou's paper to suggest the nature of the errors, a major complication in Christou's work may be the heat treatment which would cause the starting alloys to be in a complex, uncharacterized, multiphase condition. All previous experimental investigations utilized well-characterized starting material quenched to form martensite from an annealing temperature in the single-phase region.

We can only speculate as to the nature of the errors leading to Christou's disagreement with previous investigators, but we must

conclude that Christou's results present an incorrect picture of the effect of nickel additions on the phase transformation in iron-nickel alloys.

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