the high pressure martensitic transformation of pure iron at 133 kbar to a Ni + Cr content of 29.85 pct reported to be all austenitic.[15] This alloy did not undergo the $\alpha \rightarrow \epsilon$ transformation. From the figure it is seen that at the low Ni + Cr additions even the Fe-Ni and Fe-Cr data fit the curve. Beyond approximately 10 pct (Ni + Cr) deviations from the curve in the binary alloys occur and a synergistic effect of the combination of both nickel and chromium is evident. At the present time, this combined Ni + Cr effect on the transformation cannot be explained. Some deviation from the curve of the Gust and Royce data[15] is also noted and is unexplainable. However, a general trend is established showing that combined alloying additions of Ni + Cr lower the pressure of the $\alpha \rightarrow \epsilon$ transformation.

Table III. Phases Present in Fe-Ni-Cr Alloys at Various Pressures

	Composition			Pct of Phase Present at:			
Sample	Pct Ni	Pct Cr	Phase	0 Kbar	25 Kbar	155 Kbar	0 Kbar
2A	8.1	18.0	α	0	95	40	70
			ϵ	0	5	60	30
			γ	100	0	0	0
2B	11.6	17.4	α	0	80	20	20
			ϵ	0	10	80	80
			γ	100	10	0	0
2C	12.3	12.5	α	0	50	20	20
			ϵ	0	0	80	80
			γ	100	50	0	0
2D	14.9	10.0	α	0	80	30	80
			ϵ	0	0	70	20
			γ	100	20	0	0

From reported measurements of stacking fault energy in Fe-Ni-Cr alloys,[28] it appears that a decrease in the stacking fault energy is not the cause of this strong interaction effect. A decrease in the stacking fault energy would promote the formation of hcp, at least from fcc. Dulieu and Nutting[28] show that increasing the nickel content of an Fe-18 pct Cr alloy increases the stacking fault energy, whereas pressure-transformation measurements show that the formation pressure of the hcp phase decreases rapidly with nickel additions in this composition range.

As in the results of the iron-manganese experiments, the extent of the $\alpha \rightarrow \epsilon$ and $\epsilon \rightarrow \alpha$ transformations is a function of the difference between the applied pressure and the initial formation pressure (they are abaric processes). The transformations also exhibit a difference between the pressure at which the forward and reverse transformations begin. This would again indicate that the transformation is martensitic in nature.

Martensite Transformation

To find out whether the transformation occurring in these alloys was martensitic, a large (0.75 in. diam by 0.050 in. thick) sample of Fe-11.6 pct Ni-17.4 pct Cr was exposed to a purely hydrostatic stress environment. This alloy was chosen because the hydrostatic pressure unit used in these experiments was limited to about 25 kbar. Thus, if the sample began to trans-

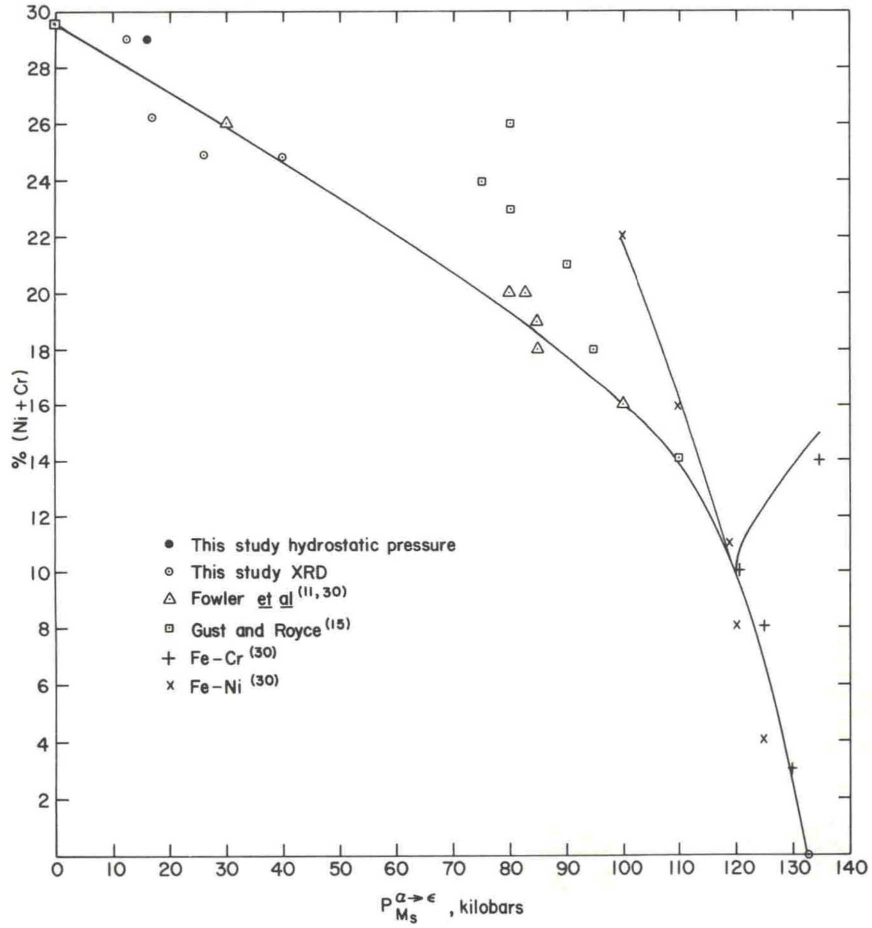
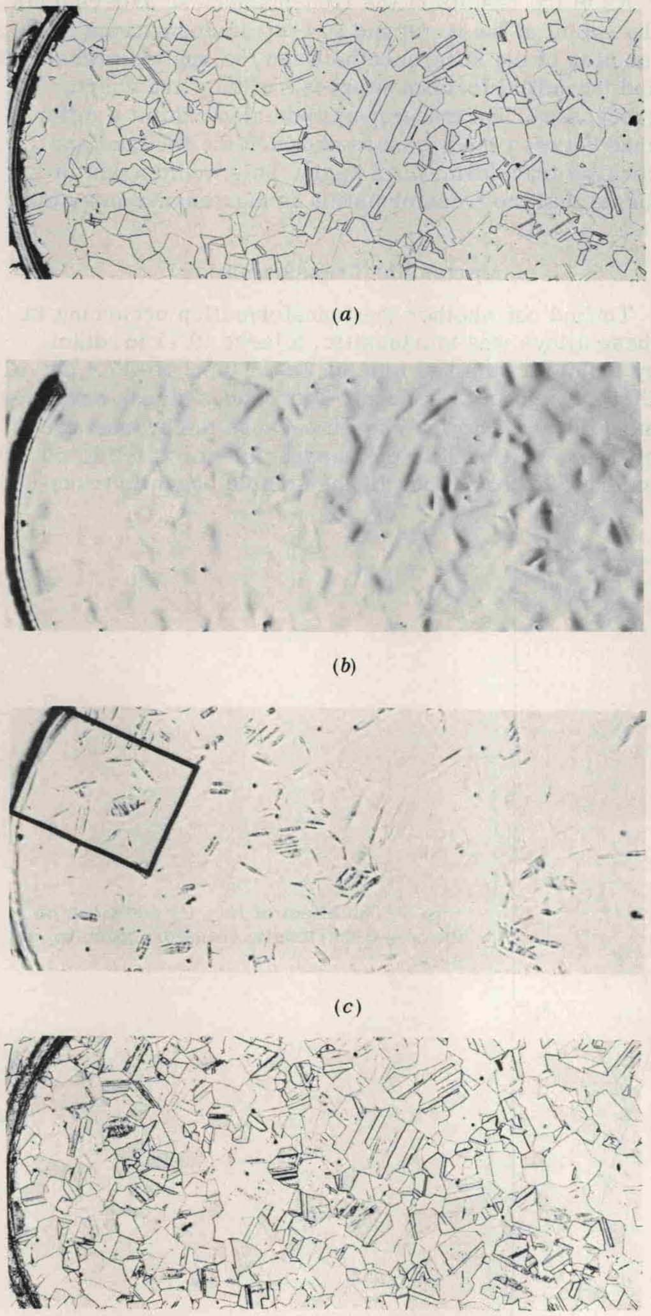


Fig. 5—The effect of Ni + Cr additions on the $\alpha \rightarrow \epsilon$ martensite transformation pressure.

form at 15 kbar—the hcp formation pressure of this alloy and the lowest observed during the program—the 10 kbar "overpressure" available would cause the formation of enough hcp martensite to permit a metallographic study of the hcp phase and, possibly, a study of its relation to both the bcc martensite and the fcc parent phase.

An annealed sample of the material was subjected to the following investigation schedule:

1) Polish and etch in 50 pct aqua regia-50 pct water
2) Photograph in incident light, Fig. 6(*a*)
3) Polish
4) Photograph in oblique light, Fig. 6(*b*)
5) X-ray
6) Pressurize to 25.5 kbar
7) X-ray
8) Photograph in oblique light, Figs. 6(*c*) and 7
9) Etch in 50 pct aqua regia-50 pct water
10) Photograph in incident light, Fig. 6(*d*).


(*a*)

(*b*)

(*c*)

(*d*)

Fig. 6.—Fe-11.6 pct Ni-17.4 pct Cr before—(*a*) and (*b*)—and after—(*c*) and (*d*)—pressurization. (*a*) etched—incident light, (*b*) polished—oblique light, (*c*) polished—oblique light, (*d*) etched—incident light. Magnification 85 times.

All of the photographs in Fig. 6 are of the same area and were taken at 100× (reduced to magnification 85 times). Fig. 7 is a photomicrograph taken at 500× (reduced to magnification 375 times). The area shown in Fig. 7 is outlined in Fig. 6(*c*). This series of photographs showing the shear and shape change associated with the transformation clearly demonstrates the martensitic nature of the high-pressure transformation. X-ray diffraction showed that the pressurized sample consisted of: the fcc parent, about 15 pct hcp, and 5 pct bcc. All of the phases gave diffraction lines corresponding to the same interplanar spacing as the phases formed during pressurization in the high-pressure X-ray diffraction camera.

After repolishing of the distorted as-pressurized surface and etching with an aqueous solution of hydrochloric acid, ammonium bifluoride, and potassium metabisulfite, the 1000× photographs (reduced to magnification 740 times) appearing in Fig. 8 were obtained. The orthogonal-appearing transformation product bounded by straight, parallel sides shown in Fig. 8(*a*) was much more common that the acicular type of structure shown in Fig. 8(*b*). These structures are typical of those found for Fe-Mn and Fe-Ni-Cr alloys.[19,23] However, the metallographic distinction between the bcc and hcp phases has not been definitely established. The white matrix is fcc.

The relatively small amount (about 5 pct) of bcc phase observed by X-ray diffraction in the hydrostatically pressurized sample was quite surprising. Since the observation from the opposed-anvil X-ray diffraction patterns indicated that the bcc phase appears prior to the formation of the hcp as a deformation-induced structure, it was expected that the bcc material should constitute a larger portion of the sample than was ob-

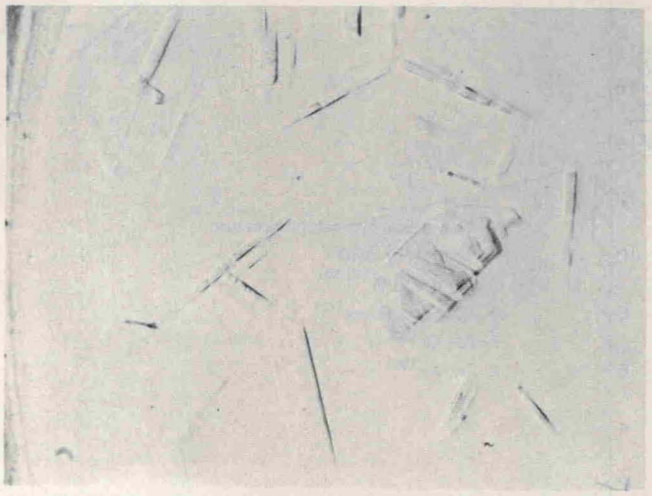


Fig. 7—Fe-11.6 pct Ni-17.4 pct Cr alloy after pressurization. The area is that outlined in Fig. 6(*c*). Oblique light. Magnification 375 times.