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INVESTIGATION OF MAGNETICALLY SOFT, HIGH-TEMPERATURE COBALT-IRON ALLOY

by John Barranger

Lewis Research Center
Cleveland, Ohio

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SUMMARY

Considerable improvement in maximum permeability is obtained in certain high-Curie-point binary cobalt-iron alloys by using ultrapure materials. The iron content of the alloys described is in the range 6 to 10 weight percent. The magnetic properties of the 9.3-percent-iron alloy are given from room temperature to 1000° C. A table of coercive force and residual induction is also included for the 9.3-percent-iron material. The results indicate that the alloys in the range 7 to $9\frac{1}{2}$ percent iron promise to be important magnetic materials for high-temperature applications such as power transformers, electrical machinery stators, and square loop devices.

INTRODUCTION

The space requirements for very-high-temperature magnetic materials for power conversion and conditioning equipment (refs. 1 and 2) have revived interest in the lesser known high-Curie-point alloys of cobalt-iron. The binary alloys in the range 5 to 21 percent iron have not only a high Curie point but also a high permeability at 25° C (refs. 3 and 4). The maximum permeability according to Bozorth (ref. 5) occurs at approximately 8 percent iron. The alloy also has a high saturation magnetization, and there are no phase changes or order-disorder transformations. The purposes of this investigation are (1) to determine the maximum permeability of the alloy in the vicinity of 8 percent iron when ultrapure materials are used and (2) to determine the effect of temperature on the maximum permeability and the hysteresis loop.

The iron content of the alloys described in this report is in the range 6 to 10 weight percent, the balance being cobalt. The magnetic properties of the 9.3-percent-iron alloy are given from room temperature to 1000° C. A table of coercive force and residual induction is also included for the 9.3-percent-iron material. The results indicate that the alloys in the range 7 to $9\frac{1}{2}$ percent iron promise to be important magnetic materials for high-temperature applications such as power transformers, electrical machinery stators, and square loop devices.

The alloys were refined and prepared by the Materials Research Corporation, Orangeburg, New York.

TEST SAMPLES AND PROCEDURE

A very-high-purity alloy was obtained by selection of high-quality starting materials and purification by electron-beam float-zone techniques. The refinement was obtained by subjecting the starting materials to three zone passes in a vacuum of 10^{-6} torr. This reduced the impurities to a total of less than 90 parts per million. The materials were then alloyed by arc melting the beam-refined metals in purified argon. Five 0.5-inch (1.27-cm) thick rods were prepared with iron contents of 6.4, 7.0, 8.0, 9.3, and 10.0 percent. Each rod was then cold rolled to a 0.012-inch (0.0305-cm) thick strip. During the cold rolling operation only the 9.3- and 10.0-percent-iron strips required an intermediate anneal. All specimens received a final stress-relieving anneal at 1020° C, a temperature which is approximately 20° C under the Curie point. In general, all the alloys had good ductility and malleability. Total impurities of the final product were less than 250 parts per million.

The alloy strip was spirally wound into a toroid with an inside diameter of 2 inches (5.08 cm). A test transformer was made by winding coils around the toroid. Nickel wire was used for the electrical winding, and boron nitride and aluminum oxide insulators were used throughout. The sample was tested in an argon atmosphere furnace from room temperature to 1000° C.

Magnetization curves and hysteresis loops were measured for all compositions by the usual ASTM ballistic methods (ref. 6). The field applied to the specimen was in the direction of rolling and was determined from the current in the windings. A fluxmeter was used to measure the induction. The accuracy of the current measuring device and the fluxmeter was ±2 percent for each instrument.

RESULTS AND DISCUSSION

The direct-current data were taken at 25°, 250°, 650°, 800°, 900°, and 1000° C. Figure 1 shows the maximum permeability as a function of the percentage of iron at various temperatures and Bozorth's maximum value of permeability at 25° C (ref. 5). The maximum permeability increases with temperature for most compositions. Although the

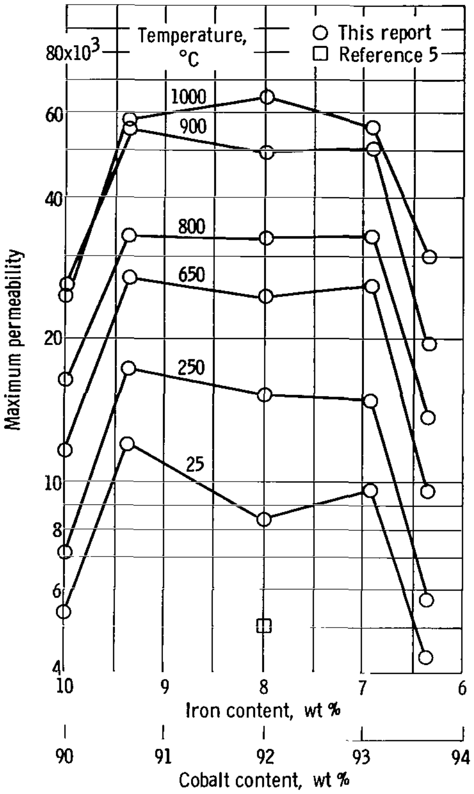


Figure 1. - Maximum permeability as function of weight percent iron at various temperatures.

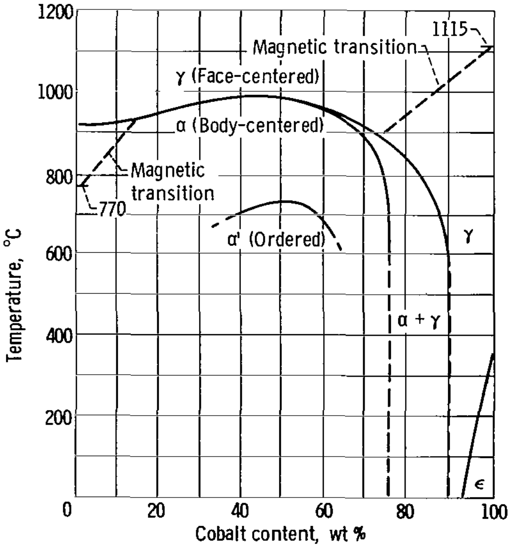


Figure 2. - Equilibrium diagram of iron-cobalt alloys.

maximum permeability at any given temperature usually occurs in the specimen that contain 9.3 percent iron, all the curves exhibit high values of permeability from 7 to $9\frac{1}{2}$ percent iron.

Examination of the 25° C curve in figure 1 shows that the maximum permeability decreases at both ends of the range. This decrease is probably due to the change to lower permeability crystalline phases at 6 and 10 percent iron. The equilibrium diagram (ref. 7) of the cobalt-iron system is illustrated in figure 2. It indicates that at 25° C there is a phase transformation from γ to $\gamma + \alpha$ at approximately 10 percent iron. The γ phase is the face-centered cubic structure, while the α phase is the body-centered cubic structure. At approximately 6 percent iron, there is a transformation from γ to ϵ, where ϵ is the close-packed hexagonal structure. Thus, the high permeability γ region of 7 to $9\frac{1}{2}$ percent iron is bounded by phase structures that have characteristically low permeabilities. Figure 1 also shows that the high permeability developed at 25° C is carried through to the high temperatures.

Since the maximum permeability at most temperatures occurs in the sample having 9.3 percent iron, all the following curves and data are for that alloy. The general behavior of this alloy is also representative of the whole range from 6.4 to 10 percent iron.

The magnetization curves for 9.3 percent iron are shown in figure 3. The permeability at low inductions increases with increasing temperature, while the magnetization at high inductions decreases with temperature. The general behavior of the magnetization curves is similar to that of pure iron or nickel. In pure iron or nickel there are no phase changes or order-disorder transformations from room temperature to the Curie point. Examination of the equilbrium diagram (fig. 2)

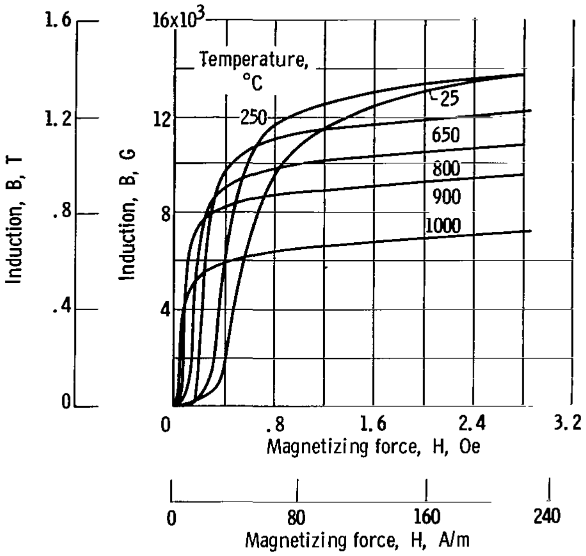


Figure 3. - Magnetization curves for alloy of 9.3 weight percent iron (balance cobalt) at various temperatures.

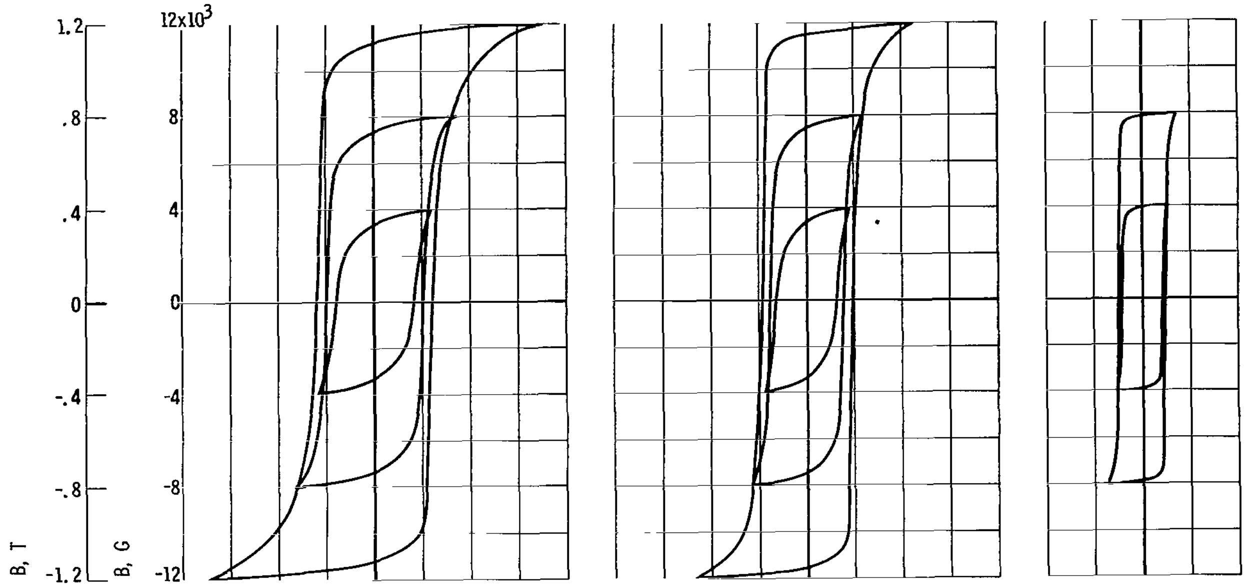
TABLE I. - COERCIVE FORCE AND RATIO OF RESIDUAL TO MAXIMUM INDUCTION FOR ALLOY OF 9.3 PERCENT IRON (BALANCE COBALT)

Temperature, °C	Maximum induction, B_m		Coercive force, H_c		Ratio of residual to maximum induction, B_r/B_m
	kG	T	Oe	A/m	
25	12	1.2	0.50	39.8	0.94
250	12	1.2	.38	30.2	.96
650	8	.8	.20	15.9	.98
800	8	.8	.15	11.9	.95
900	8	.8	.08	6.4	.94
1000	4	.4	.05	4.0	.85

shows that the 9.3-percent-iron alloy also falls into this category; hence, it behaves in a similar way.

The alloys exhibited good temperature cycling stability. During three successive temperature cycles from 25° to 1000° C the material essentially retraced the previous magnetization curves.

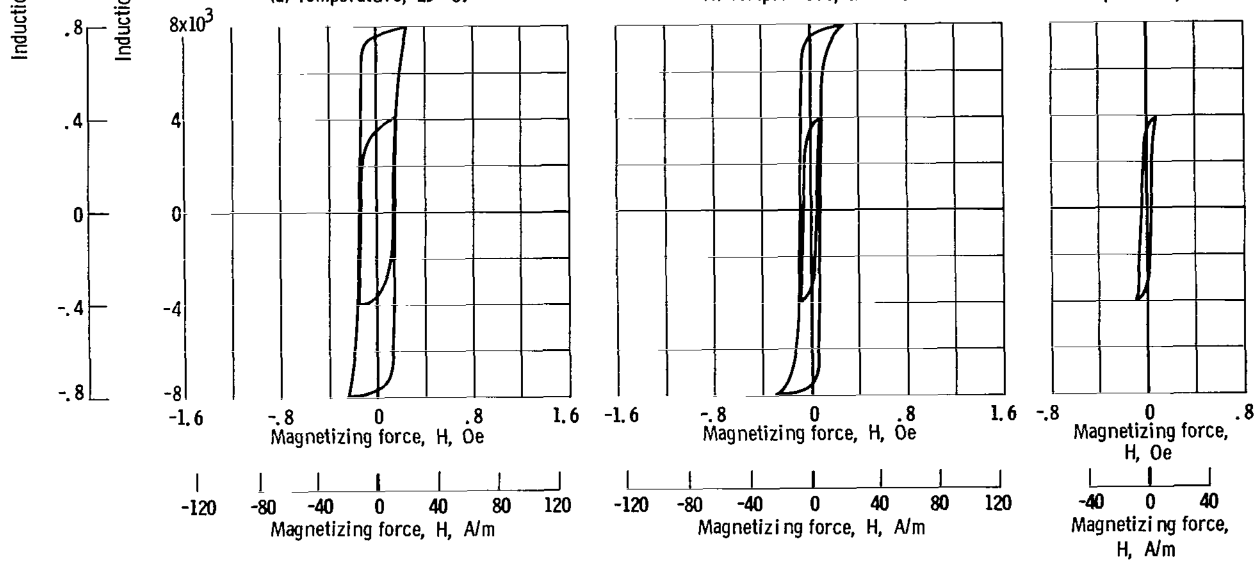
The hysteresis loops for selected values of maximum induction of the 9.3-percent-iron alloy are illustrated in figure 4. Numerical values obtained from these curves are included in table I. The hysteresis loss and coercive force continuously decrease with



(a) Temperature, 25° C.

(b) Temperature, 250° C.

(c) Temperature, 650° C.



(d) Temperature, 800° C.

(e) Temperature, 900° C.

(f) Temperature, 1000° C.

Figure 4. - Hysteresis loops for alloy of 9.3 percent iron (balance cobalt) at various temperatures.

temperature for a given induction. The high values of the ratio of residual to maximum induction suggest that the material is suitable for square loop applications.

These alloys have the highest Curie point of all known magnetically soft materials. They have many desirable magnetic properties such as high permeability, low hysteresis loss, high saturation magnetization (19 000 G or 1.9 T, ref. 5), and good temperature stability. They are also easy to fabricate into thin sheets. As a result of these characteristics, the 7 to $9\frac{1}{2}$ percent iron - balance cobalt alloys promise to be important basic materials for high-temperature applications such as power transformers, electrical machinery stators, and square loop devices.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 22, 1966,
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