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Cunife Wire Magnets of Small Size

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A ductile permanent-magnet alloy, having a composition of 60 percent of copper, 20 percent of nickel, and 20 percent of iron, was cold-drawn from wire, 25 mils in diameter to 5 mils in diameter. Demagnetization curves were obtained for several sizes of the wire in the cold-drawn state. These wires were then given a heat treatment and again demagnetization curves were obtained. Values of coercivity, retentivity, and maximum energy product are compared for various wire diameters. Although the magnetic properties were adversely affected by the cold-working, they were substantially improved by the heat treatment.

1. Introduction

Most of the commercially available permanent-magnet materials of high coercivity are mechanically hard and brittle and must be cast or sintered into the required shape for use. A magnet alloy of approximately 60 percent of copper, 20 percent of nickel, and 20 percent of iron (called Cunife or Cunife I by its producers in the United States) has an unusual combination of magnetic and mechanical properties. Although it has a coercivity of several hundred oersteds, Cunife is so ductile that it is possible to cold-reduce it considerably.

Several investigators [1,2,3] [1] have reported on the magnetic properties of Cunife wire and on the effects of cold-working and subsequent heat treatment. Their results have shown that even if the material is cold-worked to the point at which the magnetic properties are adversely affected, the initial magnetic properties may be recovered or improved by a simple heat treatment or baking. These reports, however, pertained only to the larger wire sizes. No data were available on the magnetic properties of Cunife drawn to wires a few thousandths of an inch in diameter.

The solution of a special magnetic problem required cylindrical magnets approximately 0.50 in. long and 0.005 in. in diameter.[2] The ductility and high coercivity of Cunife made it appear suitable for this application, and the present investigation was undertaken in order to evaluate it.

2. Material

The commercial material used in this investigation had a composition of 19.3 percent of nickel, 19.5 percent of iron, and 60.4 percent of copper, and was supplied by the maker in the form of wire with a diameter of 0.025 in. and in the heat-treated condition. This wire was cold-reduced from 0.025 to 0.020 in. through tungsten carbide dies with five passes. Diamond dies were used for the further reduction from 0.020 to 0.005 in. with 21 passes. Potassium soap was used as the lubricant for all passes, and no heat treatment was given the wire at any time during the reduction from 0.025 to 0.005 in. At various stages of reduction, samples were cut from the coil of wire for later measurement.

3. Heat Treatment

The magnetic properties of the cold-drawn Cunife wire may be markedly improved by properly heat-treating the wire. Since the maximum temperature at which the wire is heated affects the final magnetic properties, several heat-treating temperatures were tried. The resulting magnetic properties for samples of 5-mil wire when heat-treated for 1 hr at various oven temperatures are shown in figure 1. During this heat-treating process the wire was embedded in iron filings to prevent oxidation. In each case the temperature of a muffle-type oven was allowed to

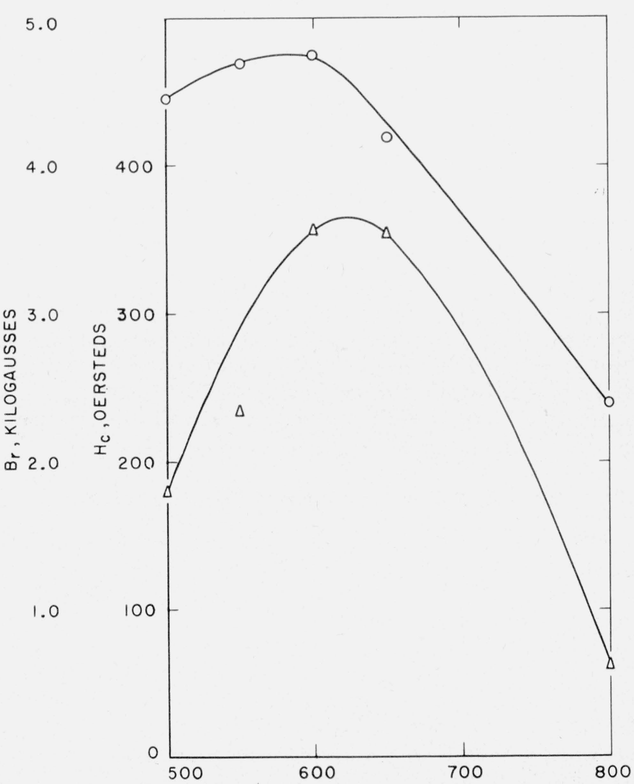

FIGURE 1. *Influence of temperature of heat treating for 1 hr on coercivity and retentivity of 0.005-in.-diameter Cunife wire.*

△, Coercivity; ○, retentivity.

[1] Figures in brackets indicate the literature references at the end of this paper.
[2] This problem was related to a classified project of the Mine Fuze Branch Diamond Ordnance Fuze Laboratory.

reach the heat-treating temperature before the wire and iron filings were placed inside. The wire and filings remained at the heat-treating temperature for 1 hr and then the heaters were turned off, the oven door opened, and the oven allowed to cool to 300° C. This cooling usually required 20 to 30 min. The sample was then removed from the oven and cooled to room temperature.

The results in figure 1 show a definite maximum value for the coercive force of Cunife when heat-treated about 620° C. This is in accord with the results obtained by Geisler [3] with the alloy Cunico. He has shown an interesting curve for the change in coercive force of Cunico as a function of aging time when held at various aging temperatures. The maximum coercive force for the three isothermals occurs at different aging time; if the proper aging time is selected the coercive force will increase, go through a maximum, and decrease when plotted as a function of aging temperature.

In order to determine the effect of oxidation on the magnetic properties, a specimen of 0.005-in. wire was placed in an oven at 610° C in an atmosphere of air and was heated for 1 hr. The wire was then slowly cooled to room temperature. The surface of this wire was then grayish black. However, the magnetic properties were the same within 5 percent as those of wire of the same size, oxidation of which had been prevented by heating in iron filings.

It might also be expected that, since wire specimens of different sizes have had different amounts of cold-working, different heat treatment might be required to obtain the best magnetic properties of wire of each size. However, using 0.020-in. (36% cold-reduced) and 0.005-in. wire (96% cold-reduced) as test samples, no such effects were found. The maximum heat-treating temperature of 610° C and 1 hr of heating time gave the optimum results for wire of both sizes.

As a result of these experiments, all wires were heat-treated in the same manner. The procedure selected was to heat the wire specimens, while embedded in iron filings, to a maximum temperature of 610° C, to hold them at this temperature for 1 hr, and then to allow them to cool slowly to room temperature. This produced wire that was bright and showed no noticeable signs of surface oxidation.

4. Apparatus and Measurements

The normal induction and demagnetization curves of the Cunife wires were obtained by using a High-H permeameter [4] and a calibrated ballistic galvanometer. The magnetizing force was measured with a flip coil, and the flux density in the wires was measured with a coil surrounding the specimen. Air flux was compensated with an auxiliary coil. The forms for the B coil and compensator coil were of aluminum, each form being 0.75 in. long with an inside diameter of approximately 0.1 in. and a wall thickness of 0.010 in. Each coil form was wound with 15,370 turns of AWG 44 varnish-coated copper wire. The Cunife specimens were cut 0.75 in. long, and a sufficient number of wires were used to have a cross-sectional area of at least 0.00040 sq in. The demagnetization curves were obtained from a maximum magnetizing force of 3,000 oersteds.

5. Results

The dependency of the coercive force on the reduction of area of the wire is shown in figure 2. Since the 0.025-in. wire was in the annealed condition initially, the percentage reduction in area is also the percentage cold-working for the lower curve. As a result of the cold reduction of the wire from 0.025 to 0.005 in., the coercive force decreased from 550 to 50 oersteds. Subsequent heat treatment restored the initial coercive force until the wire was reduced in area more than 85 percent, or to a diameter of approximately 10 mils. Further reduction in area caused a sharp decrease in the values of the coercive force, H_c; for the heat-treated 0.005-in. wire, H_c was only 60 percent of the value for the 0.025-in. wire.

This sharp decrease in coercive force at the smallest sizes of wires studied is of special interest. Since the major role in production of coercive force in Cunife is believed to be due to strain disregistry between a precipitate and the matrix, it is quite likely that for the smaller sizes of wire the severe cold-working has so distorted the grains that some of the effects of distortion may persist even after the wire has been aged. As shown in figure 2, the coercive force of the cold-drawn wire continually decreases as the cold-working increases. However, aging will more than restore the initial coercive force because of the preferred orientations as a result of cold working [5, 6, 7]. If the cold-working exceeds the optimum amount for the small wires, then the initial coercive force of the larger wire size cannot be regained, indicating that the anisotropy of the alloy was changed.

Figure 3 shows that the value of the residual induction, B_r, remained approximately constant until the reduction in area exceeded 80 percent, then decreased sharply for further increases in cold reduction.

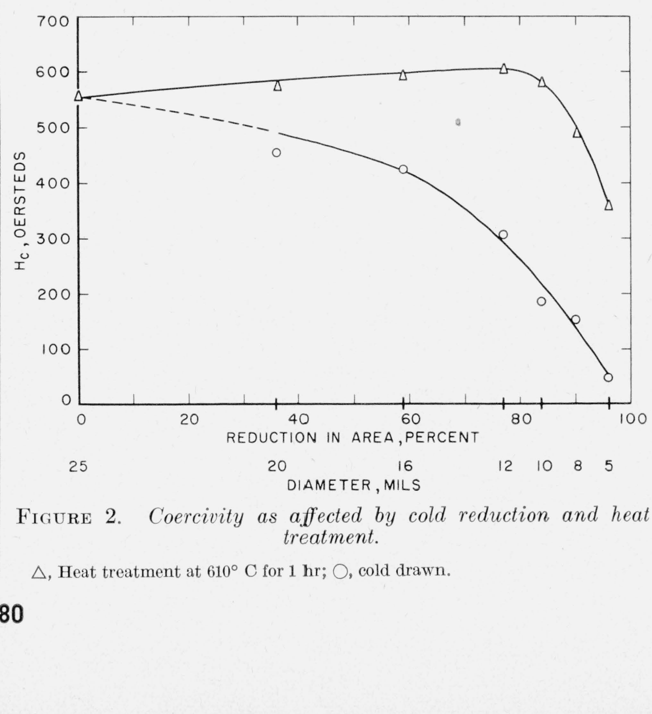

FIGURE 2. *Coercivity as affected by cold reduction and heat treatment.*

△, Heat treatment at 610° C for 1 hr; ○, cold drawn.

After the successive samples of wire were heat-treated, the residual induction, B_r, for each wire size, increased to or exceeded the initial value for the 0.025-in.-diameter wire.

The shape of the residual induction curve for the aged condition shows no dependence on wire size. This can be explained on the basis of the accepted idea that the value of residual induction for alloys depends primarily on composition and the amount of ferromagnetic phase, while strain and structure are of secondary importance.

The relationship between the maximum energy product, $(B_dH_d)_m$, and the reduction in area is shown in figure 4. For the cold-worked condition, the decrease in the maximum energy product is small until a 50-percent reduction in area of the wire is reached. For greater cold-working, $(B_dH_d)_m$ decreases quite rapidly. The heat-treated materials show a gradual increase until the reduction in area approaches 80 percent, and then the curve dips and a rapid decrease in $(B_dH_d)_m$ occurs.

The information contained in figures 2, 3, and 4 is shown in figure 5 in a different manner. The upper curve is for the ratio $(B_r)_{cw}/(B_r)_{ht}$ as a function of the diameter of the Cunife wire. Here, as well as later, the subscript *cw* designates the cold-worked condition and *ht* designates the heat-treated condition. This curve shows that the value of B_r is practically independent of the cold-working until the wire has been reduced to about 8 mils.

This figure also contains the data for the ratios $(H_c)_{cw}/(H_c)_{ht}$ and $[(B_dH_d)_m]_{cw}/[(B_dH_d)_m]_{ht}$ as functions of wire diameter. The points for both sets of data fall along the same curve and both indicate the improvement in magnetic properties that results from the proper heat treatment for the cold-worked wire.

The demagnetization curves for heat-treated Cunife wires of diameters 0.005, 0.012, and 0.020 in. are shown in figure 6.

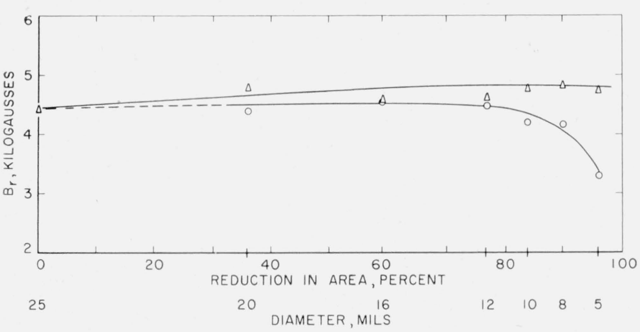

FIGURE 3. *Retentivity as affected by cold reduction and heat treatment.*

△, Heat treatment at 610° C for 1 hr; ○, cold drawn.

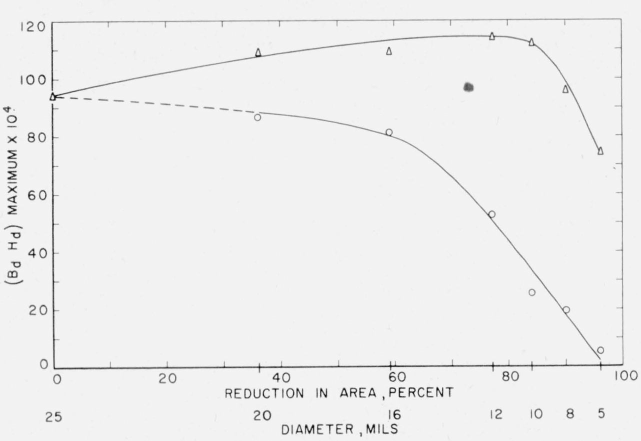

FIGURE 4. *Maximum energy product as affected by cold reduction and heat treatment.*

△, Heat treatment at 610° C for 1 hr; ○, cold drawn.

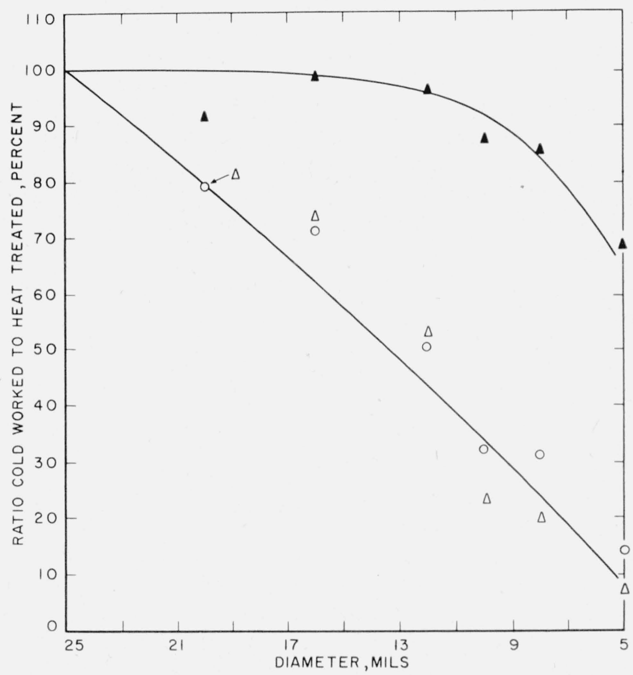

FIGURE 5. *Relative properties of cold-worked and heat-treated Cunife at different diameters.*

▲, $(B_r)_{cw}/(B_r)_{ht}$; ○, $(H_c)_{cw}/H_c)_{ht}$; △, $[(B_dH_d)_m]_{cw}/[(B_dH_d)_m]_{ht}$.

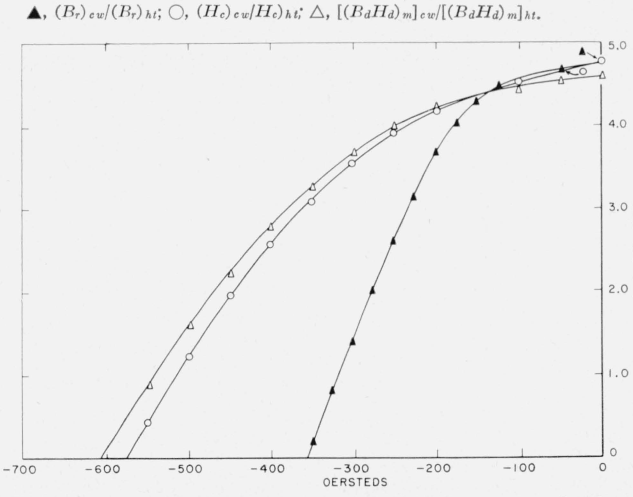

FIGURE 6. *Demagnetization curves for 5-, 12-, and 20-mil Cunife wire after heat treatment at 610° C for 1 hr.*

▲=0.005; △=0.012; ○=0.020.

It is possible to improve the magnetic properties of 0.005-in.-diameter wire by starting the drawing process from a heat-treated wire having a smaller diameter than 0.025 in. This of course will require less cold-working in reducing the wire to 0.005 in. For example, a 0.012-in.-diameter wire, in the heat-treated condition, was cold-drawn to 0.005 in. Wire samples of diameter 0.010, 0.008, and 0.005 in. were heat-treated and measurements made of their magnetic properties. The results obtained for the coercive force, H_c, and residual induction, B_r from wires drawn from 0.012 and 0.025 in. are given in the following table:

Wire diameter	H_c		B_r	
	Initial wire diameter, 0.012 in.	Initial wire diameter, 0.025 in.	Initial wire diameter, 0.012 in.	Initial wire diameter 0.025 in.
in.	*Oersteds*	*Oersteds*	*Kilogausses*	*Kilogausses*
0.010	625	580	4.6	4.8
.008	610	490	4.6	4.8
.005	520	360	4.6	4.8

Figure 7 shows the relative effects of cold-working and heat treatment on the small sizes of Cunife wire when the starting diameters of the heat-treated wires are 0.025 and 0.012 in.

6. Conclusions

Permanent magnets as small as 0.005 in. in diameter may be cold-drawn from commercially available Cunife wire. If the cold-drawn wire is subjected to a simple heat treatment, the permanent-magnet properties of the material are substantially improved. The magnetic properties for the smallest wire sizes, resulting from the final heat treatment, are apparently affected not only by the diameter of the wire but also by the cold-working.

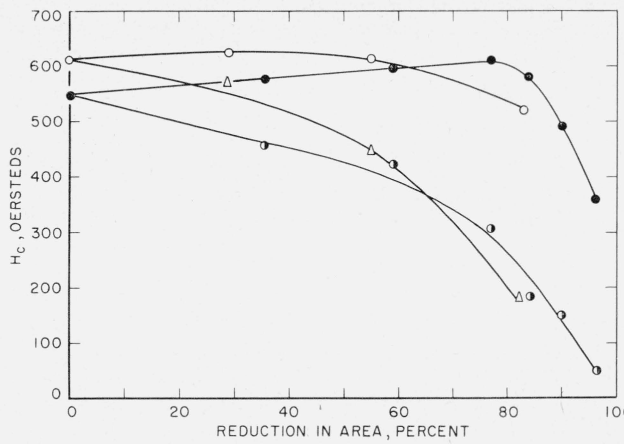

FIGURE 7. *Coercivity as affected by cold reduction and heat treatment at 610° C for 1 hr when initial wire diameters are 0.025 and 0.012 in.*

●, Heat treatment; ◑, cold drawn for 0.025-in. wire.
○, Heat treatment; △, cold drawn for 0.012-in. wire.

7. References

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