May 25, 1948. J. K. STANLEY 2,442,219

MAGNETIC ALLOY

Filed Oct. 30, 1946 2 Sheets-Sheet 1

Fig. 1.

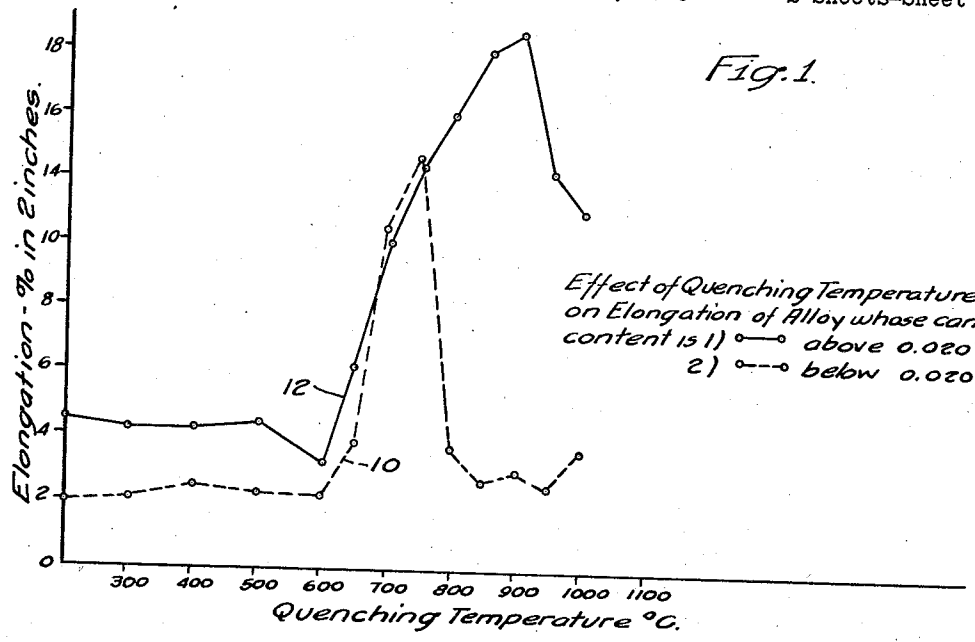
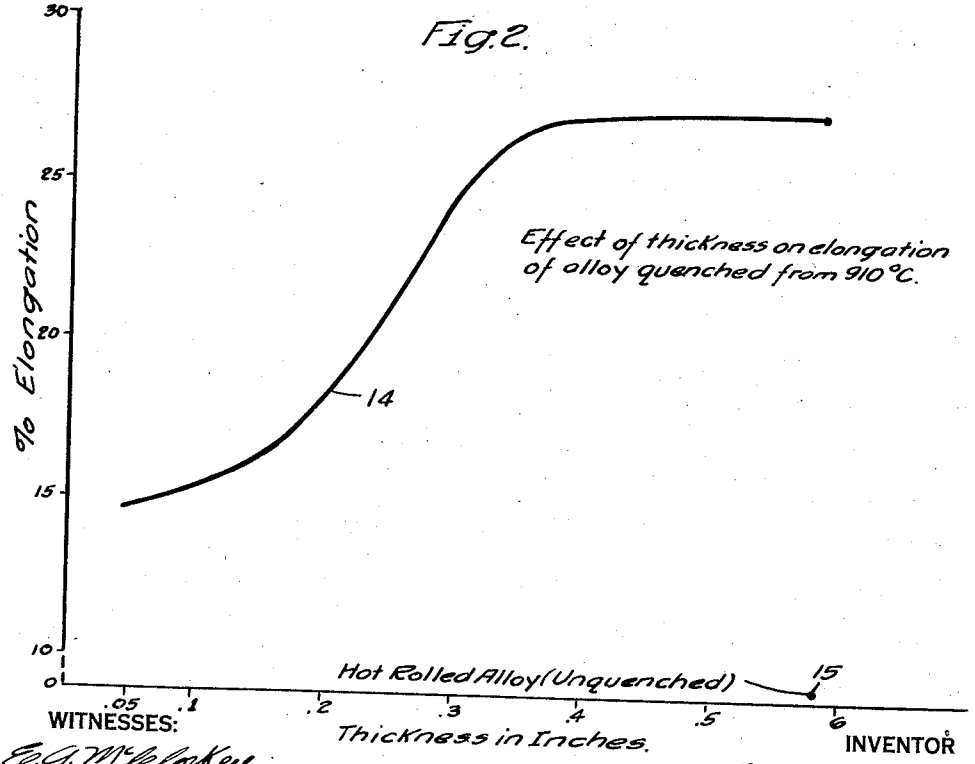


Fig. 2.



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Filed Oct. 30, 1946 2 Sheets-Sheet 2

Fig. 3.

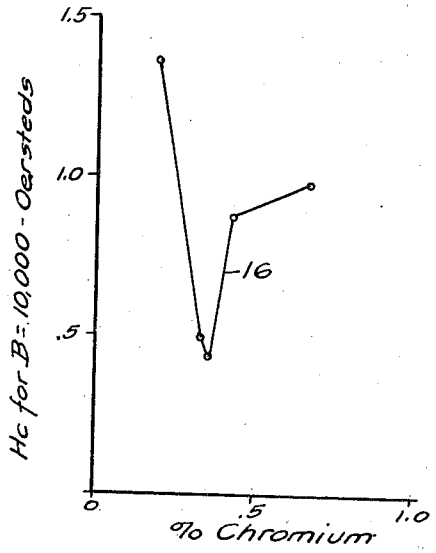


Fig. 4.

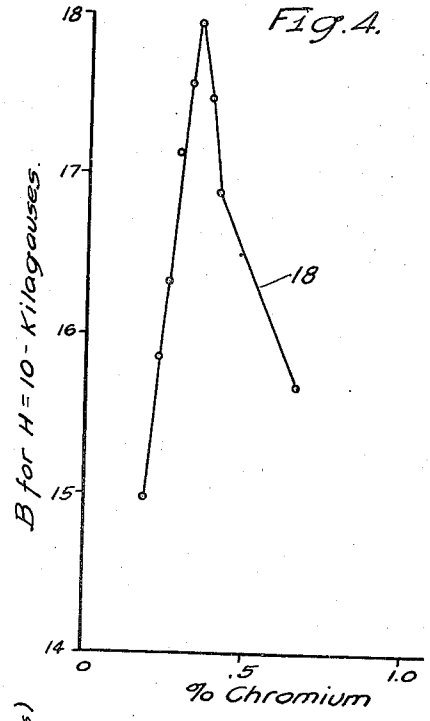


Fig. 5.

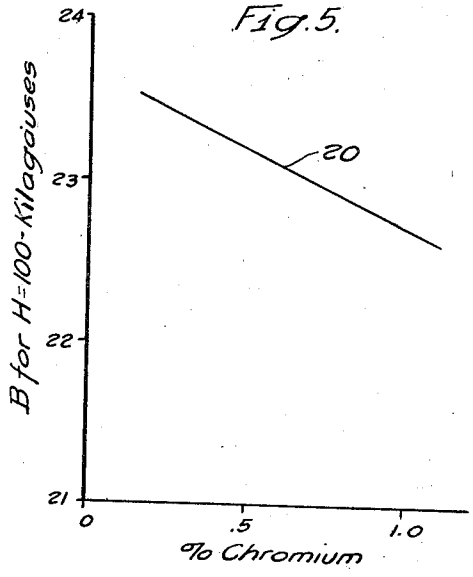
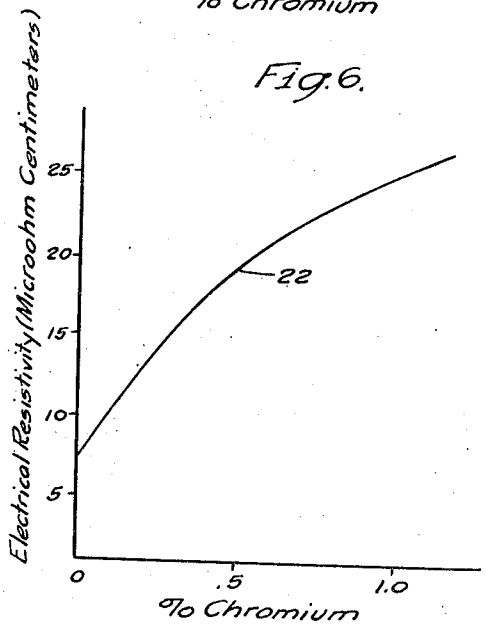


Fig. 6.



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UNITED STATES PATENT OFFICE

2,442,219

MAGNETIC ALLOY

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Application October 30, 1946, Serial No. 706,583

2 Claims. (Cl. 75—123)

1

This invention relates to alloys and in particular to magnetic alloys of the iron-cobalt type.

Heretofore, alloys of iron and cobalt have been avaliable for use as magnetic material in the manufacture of electrical apparatus. In practice, it has been quite difficult to process the known iron-cobalt alloys as they are quite brittle. Where it has been found possible to process the alloys, such workable alloys did not have as high an electrical resistivity as is required of the metal where the metal is to be employed in alternating current applications with the result that losses due to eddy currents were not as low as desired.

One object of this invention is to provide a magnetic alloy of iron, cobalt and chromium.

Another object of this invention is to provide an iron-cobalt alloy containing a small but effective amount of chromium as an essential element thereof and which will have a high saturation.

Other objects of this invention will become apparent from the following description when taken in conjunction with the accompanying drawings, in which:

Figure 1 is a graph, the curves of which illustrate the quenching response of the alloys to the carbon content on the elongation characteristics of the alloy;

Fig. 2 is a graph, the curve of which illustrates the effect of thickness of the quenched alloy on the elongation, and

Figs. 3, 4, 5 and 6 are graphs the curves of which illustrate the effect of the chromium content on the magnetic and electrical characteristics of the alloy.

The alloy of this invention comprises from 34.5% to 35.5% cobalt, from 0.30% to 0.55% chromium, less than 0.005% carbon and the balance substantially all iron. The cobalt content is selected at that value for which maximum saturation occurs in the iron-cobalt system together with low magnetic anistrophy so that the resulting alloy will have the same magnetic quality in all directions.

As the binary iron-cobalt alloys are quite brittle, such compositions are modified in accordance with this invention by the inclusion of from 0.30% to 0.55% chromium to improve the strength of the alloy and so change its structure that the resulting alloy can be hot rolled without fracture. While chromium within the range indicated makes it possible to hot roll the alloy it is also found that such chromium contents also improve the electrical resistance of the alloy rendering such alloy better suited for use in electrical apparatus.

2

Although the final carbon content is given as less than 0.005%, in making the alloy the carbon content is initially maintained at between 0.02% and 0.10% to improve the forgeability characteristics of the alloy and to render it responsive to a quenching treatment as will be explained more fully hereinafter.

In making the alloy, a small amount of carbon in an amount equivalent to 0.1% of the charge to be melted is deposited in the bottom of the melting crucible for deoxidation purposes after which the proper proportions of unannealed iron and unannealed cobalt is charged, a protective atmosphere of hydrogen being employed to prevent oxidation of the iron during the melting. After the charge is molten, the slag is removed and about 0.1% titanium and 0.1% silicon are added as deoxidizers. Sufficient deoxidizing elements are added to complete the deoxidation of the melt after which from 0.4% to 0.45% chromium and about 0.05% carbon are added to the melt. Sufficient carbon is added to insure the retention of at least 0.02% carbon in the cast alloy. When all of the additions are completely melted the molten alloy is poured into a chill mold and an ingot having a composition of 34.5% to 35.5% cobalt, .30% to .55% chromium, 0.2% to .10% carbon and the balance substantially all iron is obtained.

In practice, the ingot is hot rolled on a suitable plate mill to a size of about 3'' thick by 6'' wide after which it is cogged at a temperature of about 950° C. by conventional practice to a one inch thick sheet bar. The sheet bar is then heated to a temperature between 900° C. and 1100° C. after which it is passed through reducing rolls to reduce it to a strip having a thickness between .05 and .10 inch and preferably between .08 and .10 inch.

As the strip leaves the hot rolls it is at red heat and preferably at a temperature between 750° C. and 950° C. The hot strip is passed directly into a quenching bath of water or the like to render it ductile. Referring to Fig. 1 the effect of the carbon content of the alloy on the quenching response is illustrated by curves 10 and 12. Curve 10 is illustrative of the iron-cobalt-chromium alloys of this invention which contain less than .02% carbon and demonstrates the effect of the quenching temperature on the elongation of such alloys. As illustrated the elongation is improved by quenching from a relatively narrow range of 700 to 760° C. and even then the elongation ob-

tained is only about 10 to 12%. Such range is too critical where the alloy is to be quenched directly as it leaves the hot reducing rolls and the ductility thus imparted is unsatisfactory.

On the other hand, if the alloy contains over .02% carbon, curve 12 illustrates that good elongation, which is a measure of ductility, is obtainable over a wide range of quenching temperatures of from 750° C. to 950° C. Such temperatures can readily be maintained in the strip as it leaves the hot rolls and it is therefore evident that the quenching response of the alloys containing over .02% carbon is of great importance from commercial processing consideration as the alloys can be quenched directly from commercial hot mills.

The curves 10 and 12 are composite curves based on a number of alloys having the iron-cobalt-chromium contents given hereinbefore and with carbon contents above and below .02% and which were hot rolled to a thickness of .05 inch and quenched from the temperatures indicated. In all cases the quenching response at the different quenching temperatures formed the general pattern illustrated by curves 10 and 12 depending upon whether or not the carbon content was above or below .02%.

Referring to Fig. 2 curve 14 is a composite curve based on tests of a representative alloy within the range of elements given hereinbefore and illustrates the effect of the thickness of the strip on the elongation when quenched from a temperature of 910° C. As illustrated, the elongation decreases as the thickness decreases it being undesirable to quench strips of less than .05 inch as the required ductility cannot be obtained. As stated hereinbefore, in accordance with this invention the strip is hot reduced to a thickness of .05 to .10 inch it being found that such sized strips containing more than .02% carbon will have an elongation of 15% or more. Preferably the strip is reduced to .1 inch or less in order to facilitate the cold rolling of the quenched strip to size. Also it is preferred that the thickness be not less than .08 inch as the thinner strips tend to buckle when quenched, being so thin that they are hard to handle although strips having a thickness of .05 inch can be quenched without attending buckling if care is exercised in handling such thin strips.

While the quenching of the hot reduced strips containing over .02% carbon from between 750 and 950° C. renders the strips ductile, the reason for imparting ductility thereto is not apparent and no reason for such a characteristic can be advanced. Apparently the ductility of such a quenched strip is not dependent upon a crystal structure change for observations have proven that there are no crystal structure changes unless the strip is heated above 950° C. Again referring to Fig. 2, the improvement in ductility imparted by quenching the hot reduced strip is illustrated by reference to the point 15 which indicates the elongation of one of the alloys subjected to the hot reducing but which was not quenched as compared with the upper right hand end of curve 14 which represents the elongation of the same hot reduced alloy strip as quenched from 910° C. The improvement in ductility imparted to the alloy strip by the quenching treatment is outstanding.

After the alloy strip is quenched to render it ductile as described hereinbefore, it can be readily cold worked as by cold rolling to a sheet having a thickness of not more than .025 inch and formed to any predetermined shape in which it is to be employed in industry. In practice the alloy strip can be readily reduced to a thin sheet having a thickness of .002 inch.

When the strip is worked to size and shape, it is then subjected to an annealing treatment consisting of heating the sheet for a period of time at a temperature between 875° and 925° C. in a non-carburizing and non-oxidizing atmosphere such as hydrogen or cracked ammonia. Preferably, if the alloy sheet has a low carbon content of from .02% to .05%, the sheet is annealed in commercialy dry hydrogen having a dew point of −30, it being found that with the incidental oxide and moisture on the alloy sheets and in the annealing furnace that the gaseous atmosphere will effectively decarburize the alloy. If, however, the carbon content of the alloy sheet is high, for example between .05% and .1%, then it is preferred to anneal the sheets in wet hydrogen having up to 3% moisture by volume to effect the decarburization of the alloy. In all cases it is desired to so decarburize the alloy during the anneal that not more than .005% carbon remains in the alloy. By reducing the carbon in this manner, a low loss material is obtained and grain growth in the alloy is hastened.

In annealing the alloy strip, the strip is subjected to the annealing temperature for a period of time of from 10 to 50 hours, the latter time being preferred as such period of time gives the grains an opportunity to grow and thereby produce a magnetic material having a low hysteresis value. In annealing the sheets, it is preferred to separate the strips by means of a suitable refractory material such as magnesia, talc or alumina, in order to prevent sticking or welding of the adjacent strips.

Referring to Figs. 3, 4, 5 and 6 the curves thereof demonstrate the advantages of having a chromium content between .30% and .55%. In Fig. 3 curve 16 illustrates the effect of the chromium content on the coercive force of the alloys, the curve being a composite curve of different alloys containing chromium as indicated. As is evident the alloys containing between .30% and .55% and in particular between .30% and .40% chromium have quite low coercive force which is a highly desirable characteristic in magnetic alloys of this type.

Curves 18 and 20 of Figures 4 and 5, respectively, represent the magnetizing forces for H=10 and H=100 oersteds for alloys having different chromium contents. The effect of the chromium content is not so critical at the higher flux densities as represented by curve 20 although there is a definite decrease in the magnetizing force as the chromium content is increased. However, at the magnetizing force of H=10, the chromium content is critical within the range of .30% to .55% and in particular between .30% and .40% chromium, there being a sharp peak at about .37% chromium.

As stated hereinbefore, the inclusion of chromium also appears to improve the resistance of the new alloy. This is evident from curve 22 of Fig. 6 which illustrates the increase in resistivity of the alloy as the chromium content is increased.

As will be appreciated in the processing of the sheet bar to the thin sheet as described hereinbefore, the alloy bar or strip may be subject to severe handling sometimes being dropped by the

operator in passing from one step of the processing to another. In order to further strengthen the alloy without detrminetally affecting its magnetic characteristics, it may be desirable to include from .05% to .20% of metal selected from the group consisting of manganese, molybdenum, tungsten, titanium or silicon in the alloy as it has been found that such elements within the range given will improve the strength of the alloy somewhat. These elements, however, do not aid in enhancing, nor do they detract from, the magnetic properties of the basic iron, cobalt and chromium alloy and satisfactory magnetic alloy sheet can be readily produced either with or without such minor quantities of strengthening elements.

As examples of some of the thin alloy sheets and their magnetic characteristics produced in accordance with this invention, reference may be had to the following table, it being understood that in addition to the cobalt and chromium contents listed the alloys have less than .005% carbon and the balance iron.

Alloy No.	Co	Cr	Anneal	B for H=10	B for H=100	Hc
163	35	.33	10 hrs. at 900° C	1,760	234	.52
164	35	.37	do	1,800	233	.45
133	35	.45	do	1,700	231	.69

Another alloy containing 35% cobalt, .54% chromium less than .005% carbon and the balance iron with .06% molybdenum to strengthen the alloy when reduced to size as described and annealed at 925° C. for 10 hours had a coercive force of 1.35 oersteds but when the annealing

period was extended to 50 hours, the coercive force decreased to .61 oersted. When thus annealed, the alloy sheet had a tensile strength of 59,000 pounds per square inch and an elongation of 3.6%.

In another alloy containing 34.5% cobalt, .41% chromium, less than .005% carbon and the balance iron with less than .20% silicon to strengthen the alloy when reduced to size as described and annealed at 900° C. for 10 hours had a coercive force of 0.68 oersted and a permeability for H=10 of 1685.

The alloys of this invention can be readily duplicated, the method described making it possible to produce thin sheets of the alloy and to fabricate it into the form necessary for utilizing the magnetic alloy as a component in electrical apparatus.

I claim as my invention:

1. A magnetic alloy composed of 34.5% to 35.5% cobalt, 0.30% to 0.55% chromium, less than 0.005% carbon, and the balance substantially all iron.

2. A magnetic alloy composed of about 35% cobalt, about 0.37% chromium, less than 0.005% carbon, and the balance substantially all iron.

JAMES K. STANLEY.

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The following references are of record in the file of this patent:

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