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PERMANENT MAGNET AND PROCESS
OF PRODUCTION

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This invention relates to permanent magnet alloys and to magnets produced therefrom which are caused to have more desirable properties as permanent magnets by a cold working treatment. The invention also relates to and includes methods of treating and producing such improved alloys and permanent magnets.

An object of the invention is the production of better and more efficient permanent magnet materials.

A feature of the present invention is the discovery that permanent magnet compositions, such as those specifically described hereinafter, may be improved by reduction of the cross section thereof by a stage of cold working during their preparation and prior to the final heat treatment. Such working is preferably accomplished by methods which produce elongation and prevent lateral spreading. Methods that have been found beneficial include swaging, rolling with grooved rolls and wire drawing. It appears that the result of improved permanent magnet properties is manifested chiefly in the direction of elongation. Reduction of thickness by such rolling of a metal sheet as permits the material to spread laterally is only partially effective.

The evidence is that materials of or produced according to the present invention generally are anisotropic and their improved properties are manifested chiefly in the direction in which the elongation takes place.

In a patent issued upon a copending application referred to below it is pointed out that there are classes of materials which, if maintained at a certain high temperature but below the melting point, assume a form known as the "gamma" phase, and if the material is thereafter cooled to around room temperature, it tends to assume the "alpha" phase and thereafter if maintained at around 500° to 800°, a finely dispersed small amount of the "gamma" phase forms in the "alpha" phase. This brief statement is to be read in the light of the information, diagrams, and discussion in the patent issued upon said parent application.

As pointed out in my copending application Serial No. 311,735 filed December 30, 1939, now Patent No. 2,298,225, dated October 6, 1942, one of the procedures for preparing permanent magnet material is to melt the material and cool it to room temperature to produce formation of the "alpha" phase and thereafter elevate the material to a higher temperature between 500° C. to 800° C. for a length of time such as is necessary to allow a small amount of the "gamma" phase

to precipitate in a highly dispersed form in the "alpha" phase. This produces dispersion hardening in the material and produces a very effective permanent magnet material. This method of forming permanent magnet materials is different and seemingly involves a different principle than that heretofore employed with respect to many others, such as alloys of iron, cobalt and molybdenum, in that, in the present instance the material is converted into a low temperature "alpha" phase and thereafter has a small amount of the high temperature "gamma" phase precipitated therein in a fine and dispersed state. In the usual case of permanent magnets hardened by precipitation the high temperature phase is preserved and a small amount of the low temperature phase is precipitated.

Attention now is directed to the fact that in some alloys of the type under discussion the "gamma" to "alpha" transformation tends to occur at low temperatures at which the transformation becomes sluggish and non-equilibrium conditions exist.

Whether this is the case or not cold rolling these alloys in grooved rolls or working them mechanically by any equivalent method causes or expedites the formation at room temperature of the "alpha" phase and brings them into equilibrium. Some alloys of this type may not change completely to the "alpha" phase at room temperature unless given the above treatment. By the rolling treatment others are changed to "alpha" phase only partially. Whether complete or partial this result is one feature and beneficial aspect of the present invention. However, there is a second feature and beneficial aspect which is due to crystal orientation. X-ray measurements confirm this and magnetic tests show the best permanent magnet properties in the direction of elongation. Either or both of these effects may be present in some degree in a particular case.

After the alloys are brought into the "alpha" phase by the combination of cooling and cold working they are raised to a temperature which brings them to the temperature which causes the precipitation in finely dispersed particles of some of the "gamma" phase. This results in the production of magnetic material having effective and desirable properties as permanent magnets in the direction of elongation. In every case care must be used not to raise the material to too high a temperature in order not to lose the effect of cold working.

A rough criterion of the desirability of permanent magnet materials which is frequently

used in practice is the product of "coercive force" and "residual induction." A more accurate figure of merit is that of "maximum energy product," which on the demagnetization portion of the hysteresis loop, is the product of induction B and magnetizing force H at a point where this product is the greatest. See Wahl, "Applied Magnetism," pages 42 to 45, inclusive.

The above criterion is independent of the matter of cost, difficulty of preparation, brittleness, availability of raw materials and other factors which must receive consideration for many practical purposes and applications. Thus a permanent magnet composition which has an absolute maximum energy product less than some other which is less available or suitable from some one or more of the above aspects may be a valuable contribution to the art, if, for example, it may be made to possess a maximum energy product greater and especially if two or three times the value it has been made to have in the past.

Among objects of the present invention are to provide better permanent magnets at little or no increase in cost; to produce useful permanent magnets from materials not hitherto known to possess permanent magnet properties to a useful extent; to improve the properties of compositions known to have useful permanent magnet properties; to produce useful permanent magnets from cheap or readily available raw materials, to increase either the product of "coercive force" and "residual induction" or the "maximum energy product" of magnetic materials, and to provide useful magnets from materials which may be worked with facility.

In general, the subject-matter of the invention or discovery comprises a group of magnetic alloys which by appropriate combined heat treatment and cold rolling or elongating treatment will have one or the other of the above-named magnetic products increased in the direction of elongation by from one hundred to several hundred per cent as compared to the material in the cast or unsuitably heat treated or unsuitably worked condition.

A feature of the invention or discovery is the lack of any necessity for quenching the material at any time in order to improve its properties; however, quenching or rapid cooling upon casting may be practiced. One of the beneficial aspects of the discovery is that the cooling rate may vary widely as convenience or necessity demands.

The alloys may be prepared in the form of rods, bars, wire or tapes. A suitable treatment for any specimen is first to give it the desired amount of cold working plus a low temperature bake. No other heat treatment is necessary. Satisfactory results have been obtained with reductions in area of 75 per cent, although this exact amount is by no means critical.

In greater detail, the material is cast, which gives it the necessary high temperature treatment; it may be given a further or special heat treatment at around 800° to 1300° C. The cooled material, which may be cooled to room temperature slowly or rapidly, and must be cooled substantially below about 600° C., is forcibly elongated by rolling with grooved rolls, swaging, drawing through dies or by combinations of these methods or by any similar method or methods so as to reduce the cross section in one or several steps over a range from a small amount to a reduction to a small fraction of the original cross section. The material is then heated to a temperature generally in the region 500° to 800° C. 75

and maintained for a substantial time if treated at the lower temperature range, one to several hours in the middle range but much less if the temperature is at the top of the range. Too high a temperature destroys the effect of the cold rolling and too low a temperature or too short a time is not adequately effective. A quenching treatment is unnecessary.

The range of compositions within the scope of this invention is:

Iron	Nickel	Copper	Vanadium
Percent 40 to 50	Percent 10 to 20	Percent 20 to 40	Percent 5 to 15

A specific example consists of 45 per cent iron, 15 per cent nickel, 30 per cent copper and 10 per cent vanadium alloyed together. When this particular composition is cast in a bar $\frac{3}{8}$ inch in diameter and cold rolled by grooved rolls down to a diameter of approximately $\frac{1}{8}$ inch, it is then heat treated for a couple of hours around 600° C. with a resultant coercive force of 160 Oersteds and a remanence of 1400 Gauss.

Carbon is generally not desired to be present in any great amount and should be limited to a maximum of around $\frac{1}{2}$ per cent. Other minor impurities may be present.

These compositions exhibit substantial permanent magnet properties and are notably improved in properties by a treatment of the kind described. They may be prepared from raw materials which ordinarily are cheap and readily available. They respond to the described treatment and exhibit magnetic properties increased around 100 per cent or more as a result of the heat treatment described as compared with identical compositions as cast. In some cases the increase in energy product due to cold rolling alone is much over 100 per cent as compared to the same material heat treated but not cold rolled.

The apparatus illustrated in the above-noted application may be used to perform the cold rolling process.

The finished magnets are magnetized by the usual methods.

What is claimed is:

1. For use as a magnet an alloy composed of 40 to 50 per cent iron, 10 to 20 per cent nickel, 20 to 40 per cent copper and 5 to 15 per cent vanadium.

2. A magnet composed of 45 per cent iron, 15 per cent nickel, 30 per cent copper and 10 per cent vanadium.

3. An article having properties adapted for permanent magnet use composed of an alloy comprising as essential constituents 40 to 50 per cent iron, 10 to 20 per cent nickel, 20 to 40 per cent copper and 5 to 15 per cent vanadium, produced by causing the alloy to pass through or into the temperature range of from 800° C. to 1300° C., cooling it substantially below 600° C., forcibly elongating the material in the cold condition, and thereafter maintaining it in the range 500° C. to 800° C. without exceeding about 800° C., whereby the material is caused to have increased ability to retain permanent magnetism in the direction of elongation.

4. The method of producing a permanent magnet which comprises composing an alloy of 40 to 50 per cent iron, 10 to 20 per cent nickel, 20 to 40 per cent copper, and 5 to 15 per cent vanadium, passing it into or through the temperature range

800° C. to 1300° C., cooling the material to the general region of room temperature, forcibly elongating the material while cold, and thereafter maintaining it at 500° C. to 800° C., cooling it, and magnetizing it along the general axis of the direction of elongation.

5 5. An article having properties adapted for permanent magnet use composed of an alloy comprising as essential constituents 45 per cent iron, 15 per cent nickel, 30 per cent copper, and 10 per cent vanadium, produced by causing the alloy to pass through or into the temperature range of from 800° C. to 1300° C., cooling it substantially below 600° C., forcibly elongating the material in the cold condition, and thereafter maintaining it in the range 500° C. to 800° C.

without exceeding about 800° C., whereby the material is caused to have increased ability to retain permanent magnetism in the direction of elongation.

6. The method of producing a permanent magnet which comprises composing an alloy of 45 per cent iron, 15 per cent nickel, 30 per cent copper, and 10 per cent vanadium, passing it into or through the temperature range 800° C. to 1300° C., cooling the material to the general region of room temperature, forcibly elongating the material while cold, and thereafter maintaining it at 500° C. to 800° C., cooling it, and magnetizing it along the general axis of the direction of elongation.

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