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PERMANENT MAGNET

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The present invention relates to permanent magnets, and, more particularly, to a permanent magnet of the age hardened type which may be shaped by hot working.

Known-permanent magnets may be divided into two types; first, those made magnetically hard by the presence of carbon; and second; those made magnetically hard by a metal or metallic compound. Typical of the first group are the older and well known types of magnet steels such as carbon-manganese, chromium, chromium-molybdenum, tungsten, and various grades of cobalt steel including cobalt-chromium and cobalt-tungsten. These steels in general may be hot worked, e. g., forged and/or rolled into the desired shape and then hardened by quenching from elevated temperature. While the residual induction or remanence of these steels, designated Br, is quite satisfactory, usually varying from about 7500 to 10,000 gauss, most of the steels of this type have low coercive force. Thus, the normal coercive force of the carbon-manganese permanent magnet steels (about .6% C, .8% Mn) is about 43 oersteds, and even in the expensive cobalt-chromium-tungsten steel (about .9% C, .30 to .85% Mn, 3.5 to 5.75% Cr, 3.75 to 7% W, 35 to 41% Co) the coercive force is only about 235 oersteds. As a result of the low coercive force, magnets made from these steels become demagnetized relatively easily and quickly and are unstable to shock and heat. Moreover, in magnets having low dimension ratio (ratio of length to diameter of a bar magnet), the residual magnetism is low.

The more recently developed precipitation hardenable permanent magnet steels have overcome many of the defects of the magnet steels of the former type. The first of the precipitation hardenable magnet steels, (Dean, Reissue Patent No. 20,800), comprised iron with molybdenum, tungsten, tantalum, or beryllium with or without cobalt. When this type of steel was quenched from the solid solution temperature, the alloys were forgeable but the coercive force was not greatly higher than in the cobalt steels, ordinarily not greater than 300 oersteds. Later the splendid permanent magnetic properties of the nickel-iron-aluminum and nickel-iron-titanium alloys with or without cobalt were discovered respectively by Mishima to whom U. S. Pat-

ents Nos. 2,027,994 to 2,028,000 were granted, and Honda who obtained U. S. Patents Nos. 2,105,652 through 2,105,658. Although the magnetic properties of these steels were quite satisfactory, the residual induction being about 5000 to 10,000 gauss and the coercive force about 130 to 920 oersteds, the nickel iron alloys with aluminum and titanium were found to be unforgeable and unmachinable, necessitating casting the magnets in the desired final shape. Any finishing, where required, had to be done by grinding. The technical difficulties of commercially producing uniform permanent magnets on an industrial scale by casting are enormous, as those skilled in the art are aware. The cast magnets tend to form flaws, pipes, and other defects, have coarse grain structure, and are so brittle that their use for many purposes, where they would otherwise find application, is impracticable, if not impossible. Attempts have been made to overcome the disadvantages of these alloys. One proposed solution was to produce the magnets of these steels by the powder metallurgy methods. See British patent to Metallgesellschaft No. 510,766 and Hensel No. 2,167,240. Another solution of the problem which has been proposed is the use of the alumino thermic method. (See Howell, 2,121,799.) Neither of these methods had as its object or result the improved forgeability of the steels of this type and each magnet produced by these methods had to be formed or cast individually. In U. S. Patents Nos. 2,124,607 and 2,170,047 forgeable precipitation hardenable alloys for permanent magnets are disclosed which contain large amounts of copper (20 to 75%) with the balance iron group metals. The magnetic properties of these high copper-containing magnet steels are markedly inferior as compared with the nickel-iron types containing aluminum or titanium.

Despite the foregoing and many other attempts to solve the outstanding problem of providing a forgeable alloy for permanent magnets having high coercive force and residual magnetism, no satisfactory solution of the problem had been discovered, so far as I am aware.

I have discovered an alloy having suitable high coercive force and residual induction for satisfactory permanent magnets which may be satisfactorily forged in the hot condition.

It is an object of my invention to provide an age hardenable alloy of the nickel-iron type having high residual induction and coercive force and which may be shaped into individual magnets by hot forging.

It is another object of my invention to provide permanent magnets made of hot forged nickel-iron alloy containing age hardening ingredients and which in the aged condition is characterized by high coercive force and high residual magnetism.

Other objects and advantages of the present invention will become apparent from the following description of my invention.

Generally speaking, my novel forgeable alloy comprises as essential ingredients nickel, iron, aluminum, and titanium in controlled, correlated and critical amounts. Within the ranges of ingredients discovered by me, the alloys may be satisfactorily hot forged within the temperature range extending from about 2475° F. to about 2000° F., and in many cases to as low as 1800° F. In the production of permanent magnets from the alloy of my invention, it is possible to cast the alloy in ingot form, hot forge the individual magnets from the cast ingot, heat treat the magnets to produce the desired magnetic properties, and finally to magnetize the permanent magnets.

The alloy of my invention is predominantly nickel and iron, the nickel varying from about 20% to about 30%. The alloying ingredients which make the nickel-iron alloy age hardenable are aluminum and titanium which are present within the controlled and critical limits of about 5% to 9.5% aluminum and 1% to 3% titanium. In producing an alloy of this composition, it is preferable to melt down the iron and nickel, for example, Armco iron and electrolytic nickel without carbon addition, in an induction furnace having a zircon or other non-carbon bearing crucible or lining. When a temperature of about 3000° F. has been reached, aluminum and titanium are added. The aluminum may be added as metallic aluminum or as an alloy of aluminum with nickel and/or iron. The titanium may be added as a ferro-titanium alloy or as a master alloy containing about 45% titanium, 15% aluminum, 20% nickel, 10% manganese and the balance chiefly iron. Where the titanium master alloy is employed, it will be apparent that the amount of aluminum added apart from the master alloy may be reduced. No slags or supplementary deoxidizers need be employed. After sufficient time has elapsed for the ingredients completely to alloy, the melt may be cast into ingot molds.

In order to forge the alloy into suitable shapes for permanent magnets, the ingots are heated to elevated temperatures and forged in the hot condition. Good forgeability is obtained within the temperature range of about 2475° F. down to 2000° F. and the alloy will withstand moderate forging down to about 1800° F. The hot malleability appears to be influenced to a marked degree by the presence of sulphur and other acid forming impurities, which are advantageously kept at a practical minimum. The hot malleable or hot working properties of the new alloy may be illustrated and demonstrated by means of a hot bend test. In conducting bend tests, a forged bar about 1/2" thick by 1" wide by 6" long is heated in an electrically controlled furnace to a predetermined temperature. It is then withdrawn from the furnace and bent double (180 degrees) with a single blow of a

steam hammer. If the test piece withstands this deformation without cracking it is designated as good; if not, it is called bad. This test, performed at intervals of about 100° F. over a

range of temperatures, gives an indication as to the hot working temperature, for the dimensions of the bend test specimens have been so chosen that a good bend at any particular temperature indicates that the material is capable of being hot worked at that temperature without cracking. The range of commercial hot workability of the new alloy as judged by the aforesaid bend test is from about 1800° F. to about 2500° F.

The new alloy in the cast condition, generally speaking, is too hard to be machinable and at the same time is not hard enough magnetically to make good permanent magnets which are acceptable to the trade. By hot working the cast alloy, the coarse dendritic structure is changed over to fine grained structure which is conducive to improved magnetic and mechanical properties. When it is desired to fabricate the wrought alloy by operations such as machining, drilling, etc., the wrought alloy can be softened by a suitable heat treatment. A satisfactory treatment for this purpose comprises heating the wrought alloy to a temperature in excess of about 1200° F., such as, for example, 1500-1800° F., and then cooling slowly from this temperature, such as, for example, at a rate of 100° per hour, as in furnace cooling. The same results can be accomplished by finishing the hot working within this temperature range followed by slow cooling in the manner described hereinabove. In this softened condition, the wrought alloy can be machined, drilled, etc., and possesses improved cold malleability. Usually, the mechanical hardness of the alloy in this condition is about 35 Rockwell C to about 40 Rockwell C. and the permanent magnetic properties of the alloy are low. In order to obtain the permanent magnetic properties desired, the alloy either in the as hot-worked condition or in the softened condition is subjected to a suitable heat treatment. Satisfactory results have been obtained by first heating the alloy to a temperature within the range of about 2000-2400° F. followed by controlled cooling to a temperature below about 1400° F. and then aging. A suitable aging treatment is to hold the alloy at a temperature of about 1000° F. to about 1400° F. for about 1/4 of an hour to about 24 hours, the shortest time being employed for the highest temperature and the longest time for the lowest temperature and intermediate times for intermediate temperatures. For industrial operations, it has been found that practical and satisfactory results can be accomplished by two methods. The first method, which might be classed as a continuous or semi-continuous method, is to heat the alloy to about 2000-2400° F. in a furnace, preferably having a controlled reducing atmosphere, and to hold the alloy for a sufficient time to impart this temperature throughout the entire body of the alloy and to remove the heated alloy from the furnace. The heated alloy is then placed in a bath of molten metal or salt or a suitable tempering furnace operating at about 1000° F. to about 1400° F. and is held therein for the required aging treatment. The second method, which might be classed as intermittent method, is similar to the first, except that the alloy heated to 2000-2400° F. is cooled by quenching in a suitable medium such as hot oil, hot water, or a blast of air, followed by the required aging

treatment. The new alloy processed in accordance with the foregoing method produces a permanent magnet possessing exceptional magnetic properties which are far superior to those possessed by any wrought magnet now on the market.

The following schedule gives the permanent magnetic properties in various conditions of a typical alloy of the present invention:

Schedule

Specimen	Treatment	B _r	H _c	B _a × H _a max.
1	As forged	6,720	425	1,220,000
2	Forged, reheated to 1800° F. for 4 hrs., slowly cooled	6,000	53	125,000
3	Forged, reheated to 2400° F., quenched in hot oil	6,550	415	1,160,000
4	Same as 3, then aged 16 hrs. at 1050° F.	6,960	453	1,350,000
5	Same as 3, then aged 3 hrs. at 1200° F.	6,930	440	1,300,000
6	Forged, reheated to 2400° F., immersed in molten lead at 1100° F. for 12 hrs.	6,970	455	1,360,000

For the purpose of giving those skilled in the art a better understanding of the present invention, the following illustrative example is given:

Armco iron containing about .011% sulphur and electronickel were melted down in a zircon crucible in an electric induction furnace without carbon addition. When the melt had attained a temperature of about 3000° F., pure aluminum and titanium in the form of the aforesaid master alloy were added to the melt. No slags or supplementary deoxidizers were employed. About 1.5 minutes after the aluminum and titanium were added, the melt was poured into ingot molds. The composition of the alloy was approximately

	Percent
Nickel	25
Aluminum	9
Titanium	2
Carbon	0.01
Iron	Balance

This alloy was hot forged into magnets within the temperature range of 2475° F. to 2000° F., reducing the cross section in the hot forging operations about 97%. After hot forging, the alloy was given a solution heat treatment at about 2400° F. for about 10 minutes and quenched in hot oil. It was then reheated for about 16 hours at approximately 1050° F. The magnetic properties were then found to be about as follows:

B _r	7,100
H _c	450
B _a H _a max.	1,300,000

The composition ranges within which hot forgeability and satisfactory magnetic properties may be obtained are relatively narrow and critical. Thus, if the nickel content falls below about 20% the alloy fails to develop good permanent magnetic properties. Above about 30% nickel, the hot malleable properties of the alloy are seriously impaired. The aluminum content may not exceed about 9.5% without substantial elimination of the property of hot forgeability. Thus, if the aluminum content is 10% or more, the alloy is not hot malleable. Similarly, titanium must not exceed about 3% or the alloy loses hot malleability. Moreover, the maximum

titanium content should not be employed with the maximum aluminum content or the alloy cannot be hot forged. On the other hand, if the minimum aluminum content is used with minimum titanium content, the magnetic properties suffer. For commercial production, ranges of aluminum and titanium of approximately 8.0% to 9.25%, usually 8.5% to 9.5%, and 1% to 3%, respectively, are preferred.

The alloy is preferably substantially free of carbon. The presence of carbon improves the hot malleability of these alloys, but due to its detrimental influence on the magnetic properties it should preferably be held to the lowest practical level, e. g., less than 0.02%.

Boron, lead, arsenic, antimony, bismuth, sulphur, selenium and tellurium are highly detrimental to the hot malleability of the alloys of the present invention and should not in any case exceed about 0.05%. Silver, tin, and phosphorus are also detrimental to the hot malleability of the alloy and should not in any case exceed about 0.10%. Calcium, strontium and barium are somewhat beneficial to the hot malleability when present in concentrations of the order of about 0.01 to about 0.02%, but are highly detrimental to hot malleability when they exceed about 0.10%. Copper, vanadium, columbium, tantalum, chromium, molybdenum, tungsten and cobalt have been found to be detrimental to the hot malleability of the alloy when present in amounts exceeding about 1%, and are preferably maintained below 1%. Manganese may be present up to about 1% without detrimentally affecting the magnetic properties.

In the example given in the specification and in the claims the term "balance iron" signifies that iron is the predominating constituent of the balance, but that it may contain impurities or other alloying elements in small amounts as set forth hereinabove.

Although the present invention has been described with reference to a particular composition, certain modifications and variations in the composition and/or method of making the permanent magnets may be made as those skilled in the art will readily appreciate. Thus, for example, zirconium may be substituted partially or wholly for titanium.

I claim:

1. A hot worked alloy capable of developing magnetic properties including high coercive force and high remanence suitable for permanent magnets comprising about 5% to 9.5% aluminum, 1% to 3% titanium, 20% to 30% nickel, and the balance iron.

2. A hot forged alloy capable of developing magnetic properties including high coercive force, high remanence and a high value for B_Hmax suitable for permanent magnets comprising about 8.5% to 9.25% aluminum, 2% titanium, 25% nickel, and the balance iron.

3. A hot forged alloy capable of developing magnetic properties including high coercive force and high remanence suitable for permanent magnets comprising about 8% to 9.25% aluminum, about 1% to 3% titanium, about 20% to 30% nickel, and the balance iron.

4. A hot worked alloy as set forth in claim 1 in which carbon does not exceed 0.02%.

5. A wrought permanent magnet having high coercive force and high remanence made of a wrought alloy comprising about 5% to 9.5% aluminum, 1% to 3% titanium, 20% to 30% nickel, and the balance iron.

6. A wrought permanent magnet having high coercive force and high remanence made of a wrought alloy characterized by hot forgeability within the temperature range of about 1800° F. to about 2500° F. and which contains about 8% to 9.25% aluminum, 1% to 3% titanium, 20% to 30% nickel, and the balance iron.

7. An age hardened wrought permanent magnet having a quality index, BH_{max} , at least about one million made of a hot worked alloy comprising about 5% to 9.5% aluminum, 1% to 3% ti-

tanium, 20% to 30% nickel and the balance iron.

8. A wrought permanent magnet made of a hot worked and age hardened iron base alloy characterized by the property of hot forgeability within the temperature range of about 1800° F. to 2500° F., and, in the aged condition, by high coercive force and high remanence, and containing about 5% to 9.5% aluminum, 1% to 3% titanium, under 0.02% carbon, 20% to 30% nickel, and the balance iron.

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