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METHOD OF FORMING FERROUS ALLOYS

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This invention relates to methods of forming ferrous alloys and more particularly to hot deformation methods of forming ferrous alloys capable of developing high energy magnetic properties.

Ferrous alloys containing aluminum, nickel, cobalt and copper, adapted primarily for use in permanent magnets are known as "Alnico" alloys. Some of these alloys contain also titanium. Such alloys with high energy magnetic properties of four million gauss-oersteds and above are hard, brittle materials which are produced by casting and grinding. Neither hot nor cold deformation of these alloys has been feasible to date.

Alnico alloys with low energy magnetic properties under two million gauss-oersteds have been hot deformed by additions of titanium, zirconium and titanium, silicon, or zirconium, silicon and titanium. Previous published work disclosed that only zirconium additions would not produce a hot deformable alloy. High energy ferrous alloys of the above types had not been previously hot deformed although some of these alloys contain up to 5.2 weight percent titanium. A method of forming ferrous alloys by hot deformation, which alloys are capable of developing high energy properties, is disclosed and claimed in our copending patent application entitled "Method of Forming Ferrous Alloys," Serial No. 64,271, filed October 24, 1960, now U.S. Patent No. 3,078,197, and assigned to the same assignee as the present application. Our present invention provides an improved method of forming such ferrous alloys.

It is an object of our invention to provide a hot deformation method of forming ferrous alloys capable of developing high energy magnetic properties.

It is another object of our invention to provide a hot deformation method of forming ferrous alloys which have high energy magnetic properties.

It is a further object of our invention to provide a hot deformation method of forming ferrous alloys capable of developing high energy magnetic properties in which a supporting material is employed.

In carrying out our invention in one form, a ferrous alloy capable of developing high energy magnetic properties is formed by melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium and up to 5.2 weight percent titanium, and the balance being iron; cooling the alloy, forming a billet of the alloy enclosed in a supporting material having a melting point above the hot working temperature of the alloy, heating the billet to a temperature in the range of 1000° C. to 1150° C., extruding the billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, and removing the supporting material.

These and various objects, features, and advantages of the invention will be better understood from the following description.

Alnico alloys with high energy magnetic properties are not hot or cold worked because of their brittleness. Our above-identified copending patent application discloses and claims that such alloys could be hot deformed in a narrow working temperature range of 1050° C. to 1100° C. We have found further, unexpectedly, that improved hot deformation is accomplished by forming a billet of the alloy to be deformed in a supporting material having a melting point above the working temperature of the alloy, heating the billet to a temperature in the range of 1000° C. to 1150° C., and deforming the billet. Materials which are strong enough to be employed as such supporting materials include iron, nickel, stainless steel, and copper.

Our research disclosed additionally that the supporting material acts also as a thermal barrier to maintain the alloy at its proper working temperature during deformation. While the thickness of the supporting material is not critical, it is necessary that the supporting material be thick enough to enable the billet formed by the alloy and the supporting material to be workable without the supporting material being punctured during the working operation.

In the practice of the present invention, 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium and up to 5.2 weight percent titanium, and the balance being iron are melted together and cooled subsequently. If it is desired, commercially available cast alloys may be employed in the melting step. A billet is formed of the alloy enclosed in a supporting material having a melting point above the working temperature of the alloy. The billet is heated in a furnace to a temperature in the range of 1000° C. to 1150° C. When the billet is so heated, the supporting material acts as a thermal barrier to maintain advantageously the alloy in this temperature range when it is then deformed to a predetermined shape and size by extruding, forging, swaging, or rolling. The supporting material improves the grain structure, strength and ductility of the alloy.

After the billet has cooled to room temperature, the alloy is then cut or further worked prior to being subjected to normal treatment to produce high energy magnetic properties therein. If it is desired, the supporting material is removed prior to further working or heat treating. The billet can be subjected after deformation to a magnetic field of 1700 oersteds during cooling to impart high energy magnetic preperties thereto.

The subsequent magnetic properties of alloys produced in accordance with this invention are equivalent to the cast properties and the mechanical properties are improved due to finer grains and lower porosity. Thus, it is possible to make small diameter rod and thin sheets that could not be made by normal casting methods. Grinding of such fabricated alloys is much easier and better surface conditions are realized. If the alloy is retained in its supporting material, additional ease of machining is accomplished.

Examples of ferrous alloys capable of developing high energy magnetic properties formed in accordance with the methods of the present invention are as follows:

A series of ferrous alloy billets were produced by vacuum or air melting as set forth in Table I. The billet di-

mensions, alloy diameters, container diameters, and die diameters are shown in Table II. After the alloys were enclosed in steel jackets having thicknesses from 0.060 inch to about 1.03 inches to form billets, each billet was heated to a temperature in the range of 1000° C. to 1150° C. as set forth in Table III. The billets were extruded with a 1250 ton press from a container through a die as set forth in Table II. The deformed billets had resulting diameters as shown in Table III. Each billet was cooled to room temperature to provide a ferrous alloy capable of developing high energy magnetic properties.

Table I

No.	Chemical Analysis (Balance is Iron)						Type of Melt
	Al	Ni	Co	Cu	Zr	Ti	
1	6.9	14.3	24.6	3.0	0.36	nil	vacuum.
2	7.6	13.8	24.2	2.7	0.22	nil	air.
3	6.7	15.1	33.7	4.1	nil	5.1	vacuum.

Table II

No.	Billet Dimensions		Alloy Diameter, inches	Container Diameter, inches	Die Diameter, inches
	Length, inches	Diameter, inches			
1	3.250	3.50	3.250	3.5625	1.50
2	7.50	3.50	3.4375	3.5625	1.75
3	5.8125	3.50	3.250	3.5625	1.00

Table III

No.	Temperature, ° Centigrade	Deformed Billet Diameter, Inches
1	1,150	1.50
2	1,050	1.75
3	1,150	1.00

While other modifications of this invention and variations of method which may be employed within the scope of the invention have not been described, the invention is intended to include such that may be embraced within the following claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A method of forming a ferrous alloy capable of developing high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., and deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape.

2. A method of forming a ferrous alloy capable of developing high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, and removing said supporting material.

3. A method of forming a ferrous alloy capable of developing high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., and extruding said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape.

4. A method of forming a ferrous alloy capable of developing high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., extruding said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, and removing said supporting material.

5. A method of forming a ferrous alloy with high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, and cooling said billet in a high energy magnetic field to impart high energy magnetic properties thereto.

6. A method of forming a ferrous alloy with high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, cooling said billet in a high energy magnetic field to impart high energy magnetic properties thereto, and removing said supporting material.

7. A method of forming a ferrous alloy with high energy magnetic properties which comprises melting together 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, and subjecting said alloy to a high energy magnetic field to impart high energy magnetic properties thereto.

8. A method of forming a ferrous alloy with high energy magnetic properties which comprises melting to-

gether 6 to 9.6 weight percent aluminum, 12 to 16 weight percent nickel, 22 to 34.5 weight percent cobalt, 0.70 to 3.5 weight percent copper, a metal selected from the group consisting of up to 0.41 weight percent zirconium, and up to 5.2 weight percent titanium, and the balance being iron; cooling said alloy, forming a billet of said alloy enclosed in a supporting material having a melting point above the hot working temperature of said alloy, heating said billet to a temperature in the range of 1000° C. to 1150° C., deforming said billet at a temperature in the range of 1000° C. to 1150° C. to a predetermined shape, removing said supporting material, and subjecting said

alloy to a high energy magnetic field to impart high energy magnetic properties thereto.

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