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METHOD OF MANUFACTURING MAGNETIC MATERIALS

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This invention relates to a method of obtaining improved magnetic properties of dispersioned-hardened alloys, for example Ni-Al-Fe alloys with or without additions. Such alloys are particularly suitable for permanent magnets.

The methods of heat treatment hitherto known for these alloys have the common feature that attention is only paid to the temperature to which the body is to be heat treated or the temperature it assumes in the course of the hardening process.

The heat treatment according to the invention on the contrary is based on recognition of the fact that the progress of the dispersion hardening process in a given small region of the material is not only governed by the heat treatment to which this region is subjected but also depends on the degree of dispersion which at a given moment is reached in the immediate proximity of the said region.

According to this inventive idea such an intense temperature gradient is maintained in the material in a given direction during the heat treatment that magnetic properties are obtained which are more advantageous than those which could be obtained in the same alloys by means of heat treatments hitherto known. For this purpose, according to the above idea the temperature gradient must be selected in such manner that the degree of dispersion in two small regions which are adjacent each other in the direction of the temperature gradient is widely different.

More particularly, at the commencement of the dispersion process the existence of such a temperature gradient will exercise a considerable influence on the progress of the dispersion process and thus on the magnetic properties eventually obtained. Since the exact temperature at which the dispersion starts is usually unknown but generally ranges between 700° and 1000° C. it is advantageous to maintain a sufficiently intense temperature gradient in the material throughout this range of temperature during the heat treatment.

The use of the method according to the invention permits of obtaining particularly, depending on the choice of the conditions, a higher value of the residual magnetism, of the product $(BH)_{max}$, of the fullness factor or of the combination of these values than has been found possible by means of the methods hitherto known in connection with the same alloys (the term fullness factor is to be understood to mean here the value of the quotient

$$\frac{(BH)_{max}}{B_r \cdot H_c}$$

In some cases it has been established that it is preferable that after the heat treatment the material should be magnetised in or opposite to the direction in which the temperature gradient was maintained during the heat treatment since in these cases magnetic properties are obtained in the said direction which are more intense than those obtained in the case of magnetisation having taken place in other directions. By magnetization corresponding to the direction of the temperature gradient is meant that the magnetic lines of force extend in the same direction as the temperature gradient and that the north pole of the magnet may be made to exist at either the high temperature or the low temperature end of the temperature gradient. It has, however, not been established for certain that the magnetising method should be used in any case that has to be dealt with.

In order that the invention may be clearly understood and readily carried into effect it will now be described more fully with reference to some few examples.

An alloy having the composition 26.5% of nickel, 12.3% of aluminium, remainder of iron with normal impurities was cast in a sand mould in the form of rods being about 300 mm. in length and having a diameter of 3 mm. In this case, if the size of the mould and the composition of the moulding sand have been effectively chosen a chilling occurs which is such that the lowermost end of the rod is cooled considerably sooner than the more upwardly situated part which receives heat for a further time from the material in the mould (temperature gradient).

A piece 100 mm. in length out of the central part of the rod had highly favourable magnetic properties (line 1 of Table I given below) after casting and magnetising in the direction of the temperature gradient which existed during chilling, it being even possible for said properties to be improved by ageing at about 650° C. (line 2 of

Table I). For comparison mention is made in line 3 of Table I of the value which could be obtained in material of similar composition treated in the optimum normal manner. From the results obtained it may be seen that a considerable improvement of the product BH_{max} and of the fullness factor had occurred.

Table I

26.5% of Ni, 12.3% of Al, remainder or iron and impurities

Heat treatment	B_r	H_c	$(BH)_{max}$	$\frac{(BH)_{max}}{B_r \cdot H_c}$
(1) Rods 3 mm. cast in sand mould	7,500	380	$1.47 \cdot 10^6$	0.51
(2) Ageing 1 hour 650° C	8,000	380	$1.60 \cdot 10^6$	0.53
(3) Normally treated	6,000	420	$1.15 \cdot 10^6$	0.45
(4) Vertically immersed in water annealed 1 hour 650° C	7,600	400	$1.50 \cdot 10^6$	0.50

In the above-mentioned example casting and hardening were united in one operation. It is, however, also possible for the casting operation and the heat treatment to be brought about separately, as may be seen from the following example.

A small rod of the same dimensions and the same composition as in the first-mentioned example but otherwise cast by any suitable method was heated as a whole in a tube furnace up to 1200° C. and then vertically immersed in cold running water at a rate of about 10 mm. per second. In this case, the part that emerges from the water remains practically redhot up to the end, whereas the part under water is cold (temperature gradient). As revealed by visual observation, the transition range covers a length of about 3 mm.

It may be observed that any part of the rod consequently traverses the temperature interval from 1000° to 700° C., which is important in connection with hardening, in less than 1 sec., presumably in about 0.1 sec. In the case of normal hardening (as occurs, for example, if the rod is immersed in the water horizontally) barely any hardening would occur at such a rate of cooling. In spite of this, the rod, after the above-described treatment and hence in the presence of an intense temperature gradient, manifests magnetic properties during hardening in the direction of the temperature gradient, said properties being highly favourable for the said forms of steel and substantially equivalent to the values obtained by the first-described casting method+ageing (cf. line 4 of Table I with line 2 of the same table).

As regards the obtainment of these favourable results the correct choice of the cooling conditions is very important; once the principle being given they can, however, be ascertained for any alloy by those skilled in the art.

It may be seen from the following example that the fullness factor in combination with a favourable $(BH)_{max}$ obtained by the use of the method described is essentially higher than 0.5, a figure which in the present state of the art is deemed the highest obtainable for nickel-aluminium alloys without cobalt for which a $(BH)_{max}$ higher than 1.2×10^6 could not hitherto be obtained in practice.

Out of an alloy of the composition of 27.8% of Ni, 13.6% of Al, 2% of Cu, remainder of iron small rods were cast in the same manner as above-described. As may be seen from the Table II given below these rods manifested abnormally high values of the fullness factor, even in the cast state, after magnetisation in the direction of the temperature interval adopted (line 1), values which still increase after ageing (line 2).

Table II

27.8% of Ni, 13.6% of Al, 2% of Cu, remainder of iron and impurities

Heat treatment	B_r	H_c	$(BH)_{max}$	$\frac{(BH)_{max}}{B_r \cdot H_c}$
(1) Rods 3 mm. cast in sand mould	7,400	185	$0.82 \cdot 10^6$	0.60
(2) Ageing 1 hour 650° C	7,900	257	$1.32 \cdot 10^6$	0.65
(3) Unilateral cooling in water	7,900	135	$0.65 \cdot 10^6$	0.61

Similar results as far as the fullness factor is concerned may be obtained by a special heat treatment in which a temperature gradient is used (Table II, line 3).

The above-described methods of casting and of unilateral immersion can only be applied to steels requiring comparatively quick cooling i. e. a cooling rate of about 20° C./sec. or higher. In this case the heat of the material in the mould or the proper heat of the material suffices to bring about the required intense temperature gradient.

In connection with magnet alloys requiring slower cooling it is necessary that during the cooling heat should be supplied on one side in order that a temperature gradient may be maintained for a longer time. This may be carried into practice in various ways. One practical example in which a "slow" magnet steel is concerned is the following:

An alloy of the composition 15% of Ni, 8.5% of Al, 23% of Co, 0.75% of Si, remainder of iron and impurities was cast in long rods having a diameter of 3 mm. These rods were slowly drawn from a furnace heated at 1200° C. into another furnace kept at about 500° C. The rate of drawing was about 1 cm. in 10 minutes, the temperature interval between 1200° and 500° C. was traversed in about 1 hour.

It may be seen from the following Table III that a high residual magnetism and a very high fullness factor are thus obtained. In line 2 mention is made of the values obtained at a corresponding cooling rate but without temperature gradient.

Table III

15% of Ni, 8.5% of Al, 23% of Co, 0.75% of Si, remainder of iron

Heat treatment	B_r	H_c	$(BH)_{max}$	$\frac{(BH)_{max}}{B_r \cdot H_c}$
(1) Treated with temperature gradient	11,400	116	$0.88 \cdot 10^6$	0.66
(2) Normally treated without temperature gradient	10,900	150	$0.55 \cdot 10^6$	0.34

What I claim is:

1. The method of improving the magnetic properties of a magnetizable body of an alloy hardenable by dispersion, comprising subjecting said body in a given direction to a temperature gradient of such intensity as to enhance the magnetizability of the body in the given direction, and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

2. The method of improving the magnetic properties of a magnetizable body of an alloy hardenable by dispersion, comprising cooling said body from a temperature of at least 1000° C., subjecting said body to a temperature gradient in a given direction, maintaining said temperature gradient at least during the temperature interval of from about 1000° C. to about 700° C., and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

3. The method of improving the magnetic properties of a magnetizable body of an alloy having as main constituents nickel, aluminum and iron, comprising cooling said body while maintaining in a given direction a temperature gradient of such intensity as to enhance the magnetizability of the body in the given direction, and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

4. The method of improving the magnetic properties of a magnetizable body of an alloy having as main constituents nickel, aluminum and iron, comprising cooling said body from a temperature of at least 1000° C., so as to bring about a temperature gradient in a given direction, maintaining said temperature gradient at least during the temperature interval of from about 1000° C. to about 700° C., and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

5. The method of improving the magnetic properties of a magnetizable material of a nickel, aluminum and iron alloy comprising, forming said material into the shape of an elongated body, heating said body to a temperature of about 1200° C., progressively immersing the body vertically into a cooling fluid so as to bring about a temperature gradient in a direction corresponding to the longitudinal axis of the body and magnetizing said body in the direction of the longitudinal axis of the body.

6. In the manufacture of a magnetizable body, the process comprising molding a nickel-aluminum-iron alloy into a body of the desired shape, chilling different portions of said body at predetermined selected rates so as to bring about a temperature gradient in a given direction through the cooling body and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

7. The method of improving the magnetic properties of a magnetizable body of an alloy having as main constituents nickel, aluminum, cobalt and iron, comprising cooling said body while maintaining in a given direction a temperature gradient of such intensity as to enhance the magnetizability of the body in the given direction, and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

8. The method of improving the magnetic properties of a magnetizable body of an alloy hardenable by dispersion, comprising cooling the body from a temperature above the dispersion temperature of the alloy to a temperature below the dispersion temperature of the alloy, maintaining in a given direction and during a temperature interval including the dispersion temperature of the alloy a temperature gradient of such intensity as to enhance the magnetizability of the body in the given direction, and magnetizing said body in a direction corresponding to the direction of the temperature gradient.

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