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# PERMANENTLY MAGNETISABLE ALLOYS AND THE PRODUCTION THEREOF

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The present invention relates to permanently magnetisable alloys and the production thereof.

It is known to produce permanent magnet alloys by a combination of the alloying elements nickel, aluminium and iron. These alloys may also contain cobalt and in addition one or more of the elements copper, titanium, silicon, tantalum and columbium. Such alloys, the properties of permanent magnetisation of which are produced by age-hardening may have contents of 5–40% nickel and 3 to 20% aluminium and where the said further elements are present, up to 40% cobalt, up to 20% copper, up to 10% titanium, up to 3% silicon, up to 3% of zirconium and up to 5% of tantalum or columbium or up to 5% of the tantalum and columbium together, the remainder being iron with the usual impurities, the proportions of the constituents of the alloy being so chosen where the optional elements are present that iron is present up to at least 30%. In the specification and claims hereof the term "consisting essentially of from 5% to 40% of nickel, 3% to 20% aluminium and the remainder iron" signifies that these three elements must be present—in the case of the nickel and aluminium within the aforesaid limits and in the case of iron in an amount at least 30%—and that any one or more of the further elements above set forth may be present within the limits also above set forth.

Alloys as aforesaid may be produced by mixing the metal constituents with one another in powder form, pressing or moulding the mixture to shape and then sintering it. The alloying elements may be incorporated in the powder in the form of initial alloys of two or more components of the final alloy. The production of the alloys by the sintering method generally guarantees the production of permanent magnetic properties corresponding to those of the alloys produced by the casting method, although there are exceptions to this rule.

I have found that particularly good results can be obtained in the production of these alloys by the sintering method by the improvement according to the present invention which consists in incorporating boron in the powdered material.

The boron may be admixed with the composition in the form of a powdered alloy. Boron in the form of ferroboron with from 2% to 50% boron is advantageously chosen.

For example two ferro-alloys which are particularly suitable are, ferroboron with about 16% boron and ferroboron with about 4% boron, it being immaterial if the initial alloy contains also a certain quantity of aluminium, for example, about 4%, and silicon, for example about 2%, in addition to boron.

In general, the content of boron should be kept within the limits of 0.01 to 0.15%, and remarkable results have been obtained, as is shown from the examples which appear hereinafter, when the boron is selected from within the narrow range of such low percentages as from .01 to .10%. These percentages are calculated on the total quantity of the materials present in the composition.

The boron addition leads to an improvement in the permanent magnetic values in that the remanence values are higher in comparison with alloys without the boron addition and the demagnetisation curve exhibits a more pronounced swelling, so that the energy product ($BH_{max}$) is considerably increased. By means of the invention $BH_{max}$ values may be obtained which are at least 25–30%, or even 50% or more higher than the $BH_{max}$ values of such alloys without the boron addition.

Coming within the range to which the invention is applicable are all "Alni" and "Alnico" alloys at present in use. These alloys can be appreciably improved in their magnetic properties by the boron addition.

Particularly good results are obtained when the alloy contains 12–18% nickel, 6–9% aluminium, 20–35% cobalt, 2–6% copper, 0–8% titanium, 0.001–.15% boron, and optionally 0.01–1.5% silicon, 0.01–1.5% tantalum/columbium, singly or severally, the remainder being iron with the usual impurities. Falling within this range of alloys are permanent magnet alloys which can be given a preferred direction of magnetisation. Advantageously titanium is present from between .1 to 3%.

The alloys can also contain 0.05–3%, preferably 0.5–1.5% of zirconium.

In other compositions to which the boron addition can be made with considerable advantage, the nickel content is from 18% to 28%, the aluminium content from 9% to 14% and the cobalt content from 0% to 20%.

As an example of the marked effect of boron in the composition for the production of permanent magnets by the sintering process, the following alloys are to be compared with one another:

*Alloy I.—Without boron in the powder composition*

| | Percent |
|---|---|
| Nickel | 13.5 |
| Aluminium | 8.0 |
| Cobalt | 24.0 |
| Titanium | 0.3 |
| Copper | 3.0 |
| Silicon | 0.05 |

The remainder iron with the usual impurities, and in the specification and claims hereof the term "the remainder being iron" signifies that the said remainder may contain in small quantities any one or more of these impurities or other minor constituents.

*Alloy II.—With boron in the powder composition*

As Alloy I, but with 0.02% boron.

After the sintering and suitable heat treatment, the following were obtained:

| | With alloy I | With alloy II |
|---|---|---|
| Remanence | 10,200 Gauss | 11,700 Gauss. |
| Coercivity | 650 Oersted | 605 Oersted. |
| $BH_{max}$ | $3.2 \times 10^6$ Gauss × Oersted. | $4.23 \times 10^6$ Gauss × Oersted. |

These magnetic properties with both alloys were measured in the preferred magnetic direction, which was produced by the known method of cooling in a magnetic field. The values are of course correspondingly lower in both cases if the alloys are not subjected to a treatment for the production of a preferred direction of magnetisation.

Examples of further compositions according to the invention are as follows:

| Al | Ni | Ti | Cu | B | Co |
|---|---|---|---|---|---|
| 11 | 21 | 1.5 | 2.5 | 0.03 | ---- |
| 10.5 | 21 | 0.6 | 6.00 | 0.02 | 9.5 |
| 8 | 17 | 2.25 | 3 | 0.075 | 16 |

The two first-mentioned alloys each have $BH_{max}$ values 10–20% higher and the third 30% or more higher than corresponding alloys without boron.

The alloys according to the invention may also contain certain impurities in the iron remainder which are brought into the alloys by the starting materials employed. It is known that as a general rule these impurities should be kept as low as possible with the permanent magnet alloys of the type to which the invention relates, although it is not harmful in certain circumstances if they are occasionally present in relatively large quantities say in total up to 1.0%. This applies more especially as regards carbon, manganese, phosphorus, sulphur, chromium, tungsten, molybdenum, and the like.

As is known, the customary boron-free permanent magnet alloys which can be age-hardened have certain properties which are detrimental to their use. In particular, the edges of the permanently magnetised elements made therefrom tend to break away especially when machining the elements to finished form, e. g., during grinding, but even during subsequent use, when the permanent magnets are subjected to vibrations, striking and impact stresses. In many cases, this breaking away at the edges during mechanical treatment, and especially during grinding, cannot be tolerated since this leads to rejection and consequently uneconomic production. Furthermore, it will readily be appreciated that permanent magnet elements which tend to break away at the edges during use cannot be employed for many purposes, because the permanently magnetised particles that break away can penetrate into apparatus of which the permanent magnets are part, for example, into an instrument casing, gear, flow of a liquid to be magnetically filtered, and the like. Such particles may then in certain circumstances cause considerable damage, especially by adhering to iron articles.

The alloys according to the invention, on the contrary, have exceptional edge strength and resistance to breaking away, either during manufacture or during subsequent use. Manufacture is therefore substantially facilitated, because sintered elements as at present produced are incompatible with the method of machining which is most frequently employed with these permanent magnets, namely grinding.

The known alloys without boron are in addition extremely sensitive to the maintenance of an optimum sintering temperature. With these alloys, it is necessary to maintain the temperature accurately to within about 3–6° C., if the permanent magnetic properties in the products are constantly to have the same high values.

This makes production difficult and frequently results in rejects which cannot always be used for secondary purposes. The process for the production of alloys containing boron may, however, be essentially simplified by the fact that, without harming the permanent magnetic properties and without deleteriously affecting the mechanical properties, such as edge strength and insensitivity to grinding, sintering can be carried out in a temperature range of 1300 to 1340° C. It is readily understandable that because of the wide limits of the range, on the one hand, the waste is obviously reduced and, on the other hand, exceptionally careful supervision of the temperature is not necessary for the operation of the sintering furnaces.



What I claim is:

1. Process for improving the structure and magnetic properties of age-hardenable permanent magnet alloys essentially made by sintering powdered material consisting essentially of from 5% to 40% of nickel, from 3% to 20% of aluminium and the remainder iron, which consists in incorporating boron in an amount of from 0.001% to 0.15% in the said material and then effecting the sintering operation on the boron-containing material.

2. Process according to claim 1 in which the boron is incorporated in the powdered material in the form of powdered ferroboron containing from 2% to 50% boron and in an amount such that the boron content of the mixture shall be from 0.001% to 0.15% of the said mixture.

3. A sintered permanent magnet alloy consisting essentially of from 5% to 40% of nickel, from 3% to 20% of aluminium, from 0.001% to 0.15% of boron and the remainder iron.

4. A sintered permanent magnet alloy according to claim 3 in which the said boron content is from 0.01% to 0.10%.

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