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## ABSTRACT OF THE DISCLOSURE

A permanent magnet comprising magnetically anisotropic particles which are preferably oriented and then bonded. The powders are composed of at least two particle fractions of different average grain size, to wit

(a) a first fraction having an average grain size in the range of about 50–250 μm.,

(b) a second fraction having an average grain size in the range of about 5–50 μm., and

(c) said magnet also containing either a third fraction of such particles having an average grain size of about <15μm. or an inorganic or organic binder, the weight ratio of $a:b:c$ being about 7:3:1.

## FIELD OF INVENTION

This invention relates to permanent magnets made from anisotropic magnetic particles which are preferably aligned and bonded to each other.

## BACKGROUND INFORMATION AND PRIOR ART

It is known that magnetically anisotropic particles can be aligned in a magnetic field or, taking advantage of the shape of the particles, by appropriate rolling, extrusion pressing etc., and can then be formed into a permanent magnet. This forming can be accomplished by compacting the magnetic anisotropic particles by application of high pressure and possibly also elevated temperature, or by sintering, or through bonding of the particles by means of an inorganic or an organic binder. As inorganic binders, one can use alloys having good ductility or low melting point which yield permanent magnets of sufficient mechanical strength. As organic binders, chemically hardening synthetic resins such as the epoxy resins can be used.

A quality of special significance for the utility of a magnet is its energy product, which should be as high as possible. A high energy product is obtained when one uses an appropriate magnetically anisotropic material and sees to its that this material—which is usually available in powder form—is present in the permanent magnet in the highest possible concentration, i.e., that it is packed to the highest possible density. By sintering previously compacted powders of brittle magnetic substances, such as the ferrites or rare earth-cobalt alloys, one can obtain packing densities of over 90%, but magnets produced in this manner are very brittle and have low mechanical strength. These properties are often a disadvantage in practical applications.

## SUMMARY OF INVENTION

The present invention has as its aim the creation of permanent magnets which have the highest possible packing density and thus a high energy product. The basic idea of the invention is to use magnetically anisotropic particles of different magnetic substances having different specific grain diameters and specific mixing ratios. Densely packed bodies made according to the proposed method may be bonded and further densified by subsequent sintering, but the resulting magnets would have the above mentioned poor mechanical properties. However, the described technique permits the preparation of magnets avoiding sinter-

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ing which have nearly the same high densities as sintered magnets and therefore also good values of remanence and energy product.

The invention is primarily concerned with the novel permanent magnet materials made from alloys of the rare earth metals with cobalt, which have a high crystal anisotropy and upon which is imparted a high coercive force by means of finely dispersing them or precipitation hardening them by means of alloying additions. The production method is also applicable, however, to other anisotropic magnet materials and mixtures of several such materials.

The magnet according to this invention, consisting of magnetically anisotropic and preferentially aligned and bonded particles, has these specific characteristics: It consists of magnetically anisotropic particles having different grain sizes, namely.

(a) a fraction of an average grain size in the range from approximately 50 to 250 μm.,

(b) a fraction of an average grain size in the range from approximately 5 to 50 μm., and

(c) a fraction of an average grain size of <15 μm.

The weight ratio of these fractions $a:b:c$ is approximately 7:3:1.

The condition that, e.g., the fraction (a) has to have an average grain size in the range between approximately 50 and 250 μm. is not to be understood that the grain size distribution should cover the entire range from 50 to 250 μm., but rather that a fraction is used which is essentially uniform in grain size and whose average grain size lies within the specified range. The size of the particles of fraction (b), which in itself has again approximately uniform grain size, is determined in such a manner that it fills the voids between the particles of the coarsest fraction (a) in an optimal manner. This is the case when the average particle sizes of the two fractions are in a ratio lying between 1:7 and 1:4. The same considerations apply to the ratio of fraction (c) to fraction (b).

Since there is a unique relationship between coercive force and particle size of magnetically anisotropic materials, one can use the above specified conditions for the particle size distribution to formulate additional selection principles which are detailed in the following:

For the magnetically anisotropic particles of an average grain size in the range 50 to 250 μm. one uses preferentially rare earth-cobalt alloys which are precipitation hardened. Such alloys contain about 10 to 25 atomic percent of one, or a mixture of several, of the following elements: Y, Sc, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, in addition to 75 to 90 atomic percent cobalt and a third element which can cause the precipitation possibly even a combination of such third elements. Especially copper has become known as such a third element which can cause the precipitation. Furthermore, a portion of the cobalt may be replaced by one or both of the elements iron and manganese in order to increase the magnetic saturation. In the production of such magnetic anisotropic materials, the rare earth-cobalt and copper are melted together, cooled and then heat treated. During this heat treatment, a finely dispersed second phase forms in the interior of the grains. This second phase, which is probably nonmagnetic, impedes the motion of the magnetic domain walls (Bloch walls) and thus increases the coercive force. When such an alloy is ground, the fracture presumably takes place mostly along the grain boundaries of the magnetic matrix. Particles having a grain size in the range of approximately 50 to 250 μm. already have a coercive force of 3,000 oersted or more and are thus useful for the production of permanent magnets.

The precipitation hardening is not restricted to copper as the precipitation-causing element. Other precipitation-

hardening rare earth-cobalt-third element alloys may also be used. The essential feature is the presence of magnetic hardening through a phase (or phases) precipitated within the grain, or alternatively, through a fine subdivision of the magnetic rare earth-cobalt-alloy into regions of a size small compared with the particle size by means of a finely dispersed second phase.

For the magnetically anisotropic particles having an average grain size in the range of approximately 5 to 50 $\mu$m., one can also use the previously described precipitation-hardened rare earth-cobalt alloys, or an $RCo_5$ alloy (R=rare earth). $SmCo_5$ for instance has an appropriately high coercive force. If one aspires to the highest possible energy product, one can for instance use $PrCo_5$ or $YCo_5$ instead of $SmCo_5$. While these alloys have a lower coercive force than $SmCo_5$ for particle sizes between 5 and 50 $\mu$m., they have a substantially higher saturation. The use of precipitation-hardened rare earth-cobalt alloys is attractive when economic considerations are in the foreground and whe the attainment of the highest possible energy product is not absolutely necessary. In this case, the low-priced precipitation-hardened -(cerium-mischmetal)-cobalt-third element alloys is especially advantageous.

Although the average particle size of this fraction is to lie between 5 and 50 $\mu$m., it should be chosen within this range such that it is again approximately $\frac{1}{7}$ to $\frac{1}{4}$ of the average particle size of the first fraction.

The especially fine grain of the third fraction of <15 $\mu$m. should, for best results, again be $\frac{1}{7}$ to $\frac{1}{4}$ of the grain size of the medium fraction. The alloys which offer themselves for this fraction are the well-known ones of rare earths with cobalt containing 10 to 25 atomic percent of rare earth. These rare earth-cobalt alloys may also be precipitation hardened. However, another more conventional permanent magnet material of sufficient coercive force in this particle size range can also be used. Examples for such a material are the barium and strontium ferrites. Preferentially, however, one will use an alloy of very high saturation such as $PrCo_5$.

In the production of permanent magnets according to this invention one proceeds as follows: the magnetically anisotropic particles having specified particle diameters are blended in the specified weight ratio. The weight ratio of the individual fractions may occasionally deviate from the specified ratio 7:3:1, since the packing density depends also on shape of the particles, and since the densities of the different fractions may be appreciably different if chemically dissimilar substances are used. It is best to determine the weight ratio of the individual fractons which yields optimum packing density for each combination by experiment. Mathematical studies have been made about the achievement of high packing density and its relation to grain size and fractional quantities. Results of such studies can, e.g., be found in the book "Perspectives in Powder Metallurgy. Fundamentals, Methods and Applications," vol. 2, Plenum Press, especially in the chapters "Mechanical Packing of Spherical Particles" by R. K. McGeary and "The Vibratory Packing of Powders" by P. E. Evans and R. S. Millman.

It is beneficial to compact the mixture further after the blending by mechanical vibration. The orientation of the magnetically anisotropic particles may be achieved before and/or during, and/or after the vibratory compacting. The final forming of the magnets is achieved in the well-known manner by application of pressure, possibly at elevated temperature, by sintering, or by means of binders. Such binders may be introduced either in liquid form or as a very fine powder whose average particle size is again best chosen in the range between $\frac{1}{7}$ and $\frac{1}{4}$ of the third, the finest, magnetic fraction. In a variation of the object of the present invention, one can use the inorganic or organic binder in place of the third, finest magnetic fraction. This binding agent—for instance ductile and/or low-melting metals or alloys, or hardenable synthetic resins—fills the voids between the grains of the other two fractions.

The magnetically anisotropic particles of rare earth-cobalt alloys for use in the production of such permanent magnets may be improved by a special surface treatment. Examples for the latter are: soaking of the particles in a nickel bath, an acid treatment, and/or deposition of tin on the surface of the particles followed by a diffusion treatment. It is known that such measures increase the coercive force and provide a protection against ageing.

Although the main objective of the invention is the preparation of magnets with an absolutely high energy product, which requires a high degree of orientation of the anisotropic particles in addition to a high density, the procedures of the invention can nevertheless also be used to optimize isotropic permanent magnets. When low production cost is a primary consideration, one can forego the particle orientation by magnetic or other means—as is done in the production of inexpensive ferrite magnets.

The invention will now be described by several examples, it being understood that these examples are given by way of illustration and not by way of limitation and that many changes may be effected without affecting the scope and spirit of the invention as recited in the appended claims.

### EXAMPLE 1

Production of the particles of the precipitation hardened alloy $SmCo_{3.5}Cu_{1.5}$ which are used in the following Examples 6, 7, 8, 11, and 12

Metallic samarium, cobalt and copper in the form of approximately pea-size pieces or wire of 2 mm. diameter were weighed out in the proportions corresponding to the above formula (332.7 g. Sm, 456.4 g. Co, 211 g. Cu). This charge, weighing approximately 1 kg., is mixed and then melted in a pure alumina crucible in an induction melting furnace under argon gas and held at approximately 1500° C. for 10 minutes. The melt is then cast into flat cold copper molds of approximately 200 g. capacity each, which are located in the furnace chamber. The casting is also done under protective gas. The alloy, which usually breaks into small pieces during the quenching due to its high brittleness, is transferred into a vacuum annealing furnace after it has completely cooled and is then heat treated for approximately 4 hours at 400° C.

The alloy is then ground with mortar and pestle, and powder fractions of the following ranges of particle size are prepared by sifting with the aid of a sieve shaker. The fractions are: <37 $\mu$m., 37–53 $\mu$m., 53–74 $\mu$m., 74–105 $\mu$m., 105–149 $\mu$m., and 149–250 $\mu$m. A portion of the powder having <37 $\mu$m. particle size was further ground for an additional 3 minutes under hexane in a laboratory vibratory mill (Spex Industries Mixer/Mill, Model 8000) and was then sifted through a copper screen with openings of 20 $\mu$m., first by shaking, then by brushing, so that two particle fractions of 20–37 $\mu$m. and <20 $\mu$m. are obtained.

A sample of the powder of 74–105 $\mu$m., which was premagnetized in a magnetic field of 26 koe. and then bonded with a two-component epoxy resin in the presence of an aligning field of 4.5 koe., shows a very nicely rectangular hysteresis loop, (BH) vs. H, having a coercive force of $_MH_c$=6190 oe. upon further comminution, $_MH_c$ initially stays practically constant, but then increases further for particle sizes below 37 $\mu$m.

### EXAMPLE 2

Production of particles of the precipitation hardened alloy $MMCo_3Cu_2$ which are used in the subsequent Examples 9, 10, and 11

(MM is the symbol used here for the commercial cerium-rich mischmetal of the approximate composition 54.5 wt. percent Ce, 26% La, 13% Nd, 5% Pr, and approximately 1.5% other rare earths and other metals.)

Mischmetal, cobalt and copper were weighed out in proportions corresponding to the above formula as was

done in Example 1. A charge weighing approximately 50 g. was then melted in an arc melting furnace with a water-cooled tungsten electrode under a protective gas mixture of 75% argon and 25% helium. To effect good homogenization, the button-shaped ingot was turned over and remelted three times. After the current is turned off, the ingot cools very rapidly in the water-cooled copper mold. Five such ingots were prepared under the same conditions, were then broken into pieces weighing between .1 and 1 g., these were heat-treated in vacuum for 4 hours at 500° C., and were then powdered and classified by sifting as described in Example 1.

Additional powder fractions of even finer grain size were prepared by further mortar grinding the powder of <37 $\mu$m. and letting it run twice through a centrifugal classifier (Bahco Micro-Particle Classifier of the H. W. Dietert Co., Detroit, Mich.). In this manner, 3 additional fractions were obtained with mean particle diameters near 28, 18 and 10 $\mu$m. according to microscopic observations.

A sample for magnetic measurements, prepared as described before from particles from 74 to 105 $\mu$m., magnetically aligned and embedded in epoxy resin, had a rectangular hysteresis loop with $_MH_c$=4320 oe.

### EXAMPLE 3

Preparation of the alloy powder of the composition SmCo$_5$ used in the subsequent Example Numbers 6 and 7

The metals samarium and cobalt were weighed out corresponding to the above formula in accordance with Example 1 (338.5 g. Sm, 661.5 g. Co). The ingot, weighing 1 kg., was then melted in the induction furnace at approximately 1450° C., was then held for ½ hour at the temperature of 1200° C. to achieve homogenization, and it was finally cooled to room temperature relatively slowly in the crucible after turning off the furnace power. The result is a nearly single-phase ingot of the intermetallic compound SmCo$_5$.

By grinding in the mortar and subsequent sifting, a powder of <105 $\mu$m. particle size was made from this alloy, and 100 g. batches were then ground in a ball mill (Szegevary Attritor Mill, Model BS–01 of the Union Process Corp. in Akron, Ohio), using steel balls of 3 mm. diameter and toluene as a grinding liquid. After a grinding period of 15 minutes the powder had a rather narrow particle size distribution with a maximum at approximately 7 $\mu$m. (=average particle size). A powder sample prepared as in Example 1 had a hysteresis loop which was slightly unsymmetric after magnetizing in a field of 22.4 koe. and showed a coercive force $_MH_c$= 17,150 oe. and a ratio of remanence-to-maximum induction of 0.92 after magnetization to the higher of the two maximum induction values.

### EXAMPLE 4

Production of the alloy powder of the nominal composition PrCo$_5$ used in Example 11

The metals praseodymium and cobalt were weighed out as in Example 1, except that an excess of approximately 2% Pr over the formula ratio was used in order to compensate the loss of Pr which is usually experienced in arc melting and so to avoid the presence of Pr$_2$Co$_{17}$ in the ingot as a second phase. The alloy was prepared by arc melting as described in Example 2 and was then homogenized at 1100° C. for 48 hours.

The alloy was then ground in mortar and ball mill as explained in Example 3. Grinding for 1 hour in the ball mill produced a powder of an average particle size of approximately 5 $\mu$m. which had a coercive force of $_MH_c$=4800 oe. and a good loop squareness (remanence divided by maximum induction=0.95).

### EXAMPLE 5

Production of the improved alloy powders of the approximate composition MMCo$_5$ used in the subsequent Example 10

An alloy of mischmetal of the composition listed in Example 2 with Co of low purity, containing approximately 0.7% Ni and 0.8% Fe, was made from 118.6 g. MM and 132.7 g. Co using the induction melting method described in Example 1.

After two hours' vacuum annealing at 1100° C. the alloy was practically single phase. By grinding with mortar and pestle and sifting, a powder fraction of a particle size <37 $\mu$m. was prepared. To increase the coercive force and to protect the particles against a loss of coercive force through aging, a zinc layer was deposited upon the surface of the particles and diffused in. To this end, the powder was intimately mixed with 5 wt. percent zinc dust and the mixture was heated in a vacuum to 450° C. for 10 minutes. The powder was then brushed through a sieve with openings of 20 $\mu$m. The fraction of <20 $\mu$m. particle size had a coercive force $_MH_c$=2700 oe.

### EXAMPLE 6

Preparation of a magnet from SmCo$_{3.5}$Cu$_{1.5}$ and SmCo$_5$

Two particle fractions of the powder of Example 1 and one component of SmCo$_5$ prepared according to Example 3 were intimately mixed in dry form by shaking them in the Spex Mixer/Mill without grinding balls. The following particle sizes and quantities were used: (a) 7 g. of the fraction 149–250 $\mu$m., (b) 3 g. of the fraction 37–53 $\mu$m., both of SmCo$_{3.5}$Cu$_{1.5}$, and (c) 1 g. SmCo$_5$-powder of approximately 7$\mu$m. average particle size. About 5 g. of this powder mixture were poured into the pressing mold described below, the pressing piston was inserted, and the entire mold was vibrated for the purpose of compaction by means of an electromechanical vibrator for a period of 10 minutes. A frequency of 170 Hz. and a maximum acceleration of 15 g. were applied. (Here, g. is the gravity constant g.=9.81 m./s.$^2$.) The pressing mold was then inserted between the pole caps of an electromagnet, the powder soaked with acetone, and the magnetic aligning field of 36 kg. was applied and turned on and off five times. Then, with the aligning field turned on, the sample was pressed by applying 9,000 kg./cm.$^2$ uniaxial pressure (perpendicular to the field). The pressing force was maintained for 5 minutes during which the liquid was first slowly squeezed out before a bonding of the particles took place.

The result was a magnet sample of density $d$=7.2 g./cm.$^2$ (approximately 85% of the density of the massive alloy) which had the following magnetic parameters, measured with a maximum field of 25 koe.: B$_r$=5100 G, $_MH_c$=5850 oe., $_BH_c$=4800 oe., (BH)$_{max}$=5.8 mgoe. The sample had poor mechanical strength and the tendency to crumble during handling.

The pressing mold used here permits the fabrication of prismatic briquets with the following dimensions: ¼ inch (~6.3 mm.) in field direction, ¾ inch (~19 mm.) normal to the field and to the pressing direction. The short dimension, in the direction of the pressing force, depends on the amount of powder used and, for this magnet, was 6.1 mm. (All magnets described in the following had nearly the same dimensions.) Inserted into the pressing mold are pole pieces made from an iron-cobalt alloy for the purpose of field enhancement, and these serve simultaneously as two walls of the pressing mold. The side walls and the pistons consist of a hardened copper-berryllium alloy. The pressing chamber can be evacuated.

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### EXAMPLE 7

#### Preparation of a magnet with improved mechanical properties from $SmCo_{3.5}Cu_{1.5}$ and $SmCo_5$

A second magnet sample was prepared exactly as in Example 6. After pressing, however, the magnet was vacuum-impregnated with a chemically hardening two-component epoxy resin of low initial viscosity (Allaco 20/20 Epoxy). After the resin had cured, which took approximately 2 hours at 40° C., the sample had practically the same magnetic data as those quoted in Example 6, but a considerably enhanced stability of shape and mechanical strength which should be sufficient for many practical magnet applications.

### EXAMPLE 8

#### Preparation of a magnet with improved mechanical strength from $SmCo_{3.5}Cu_{1.5}$ with a soft metal binder

A magnet sample was prepared following essentially the procedures described in Example 6. As the finest powder fraction (c), however, two grams of a very fine-grained tin powder were now used in the place of the one gram $SmCo_5$. The tin powder had a relatively broad particle size distribution with an upper limit of about 10 $\mu$m. and had been obtained by centrifugal separation of a fine-grained commercial tin powder of spherical particles. During the magnetic alignment of the particles before pressing, no liquid was added this time to increase the particle mobility. Instead, also with the objective of facilitating the alignment in the field, the pressing mold was tapped approximately 20 times with a hammer from each side while the aligning field was on. The pressed magnet sample had excellent mechanical strength and stable edges. The magnetic data were: $d=7.5$ g./cm.$^3$, $B_r=4900$ g., $_MH_c=5800$ oe., $_BH_c=4600$ oe. and $(BH)_{max}=5.3$ mgoe.

### EXAMPLE 9

#### Preparation of a magnet from $MMCo_3Cu_2$

Three size fractions of the powder of the alloy $MMCo_3Cu_2$, prepared as described in Example 2, were mixed as in Example 6, vibratory-compacted and pressed in a magnetic field. The particles, sizes and quantities used were: (a) 7 g. of the fraction 149–250 $\mu$m., (b) 3 g. of the fraction 37–53 $\mu$m., (c) 1 g. powder of 10 $\mu$m. average particle diameter. The magnet thus produced had a density of 7.0 g./cm.$^3$, $B_r=4800$ g., $_MH_c=4200$ oe., $_BH_c=3700$ oe., $(BH)_{max}=4.6$ mgoe. Before the measurement the sample was impregnated with epoxy resin as described to impart sufficient mechanical strength to it.

### EXAMPLE 10

#### Preparation of a magnet from $MMCo_3Cu_2$, $MMCo_5$ and barium ferrite

A powder fraction (a) made of $MMCo_3Cu_2$ particles in the size range 74–105$\mu$m., a fraction (b) of $MMCo_5$ with less than 20 $\mu$m. particle size, stabilized with zinc as described in Example 5, and a part (c) of barium ferrite having a mean particle size of about 2 $\mu$m., which had been obtained by grinding a sintered Indox 2 magnet in the Spex mill, were treated as follows: 7 g. of (a), 3 g. of (b) and 0.8 g. of (c) were stirred into 2.5 cm.$^3$ of liquid acrylic lacquer. (GC Koloid-Clear Acrylic of the G. C. Electronics Co.; contains 40% of solids, methylmethacrylate in the form of colloidal particles of approximately 0.1 $\mu$m. diameter, according to company literature.) The solvent was evaporated in a stream of warm air while the mixture was stirred, and the resulting dry, crusty powder was brushed through a sieve of a mesh width 105 $\mu$m. The powder was then transferred into the pressing mold and pressed as in Example 6, except that no vibration and no aligning field were applied.

The resultant magnet showed good mechanical coherence, was magnetically almost isotropic, and had the fol-

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lowing properties after magnetizing in the field of 25 koe.: $d=5.8$ g./cm.$^3$, $B_r=3100$ g., $_MH_c=3800$ oe., $_BH_c=2900$ oe., $(BH)_{max}=2.2$ mgoe.

### EXAMPLE 11

#### Preparation of a magnet from $SmCo_{3.5}Cu_{1.5}$, $MMCo_3Cu_2$ and $PrCo_5$

A component (a) of 7 g. $SmCo_{3.5}Cu_{1.5}$ of particle size 74–105 $\mu$m., treated as explained in Example 1, a component (b) of 3 g. $MMCo_3Cu_2$ of a particle fraction having approximately 18$\mu$m. average particle size which was prepared by means of the centrifugal classifier as explained in Example 2, and a component (c) of 1 g. $PrCo_5$ ballmilled according to Example 4, having a particle size of about 5 $\mu$m., were intimately mixed using procedure of Example 6, then compacted by vibration, magnetically aligned, and then pressed. This yielded a magnetic sample with the following properties, measured with 25 koe. parallel to the aligning field: $d=7.4$ g./cm.$^3$, $B_r=5200$ g., $_MH_c=5300$ oe., $_BH_c=4600$ oe., $(BH)_{max}=6.0$ mgoe.

### EXAMPLE 12

#### Preparation of a magnet from $SmCo_{3.5}Cu_{1.5}$ with only one particle size fraction

In order to more clearly demonstrate the advantages of mixing 2 to 3 particle fractions which are mixed with a nearly optimal ratio of average particle sizes and volume fractions and then nearly optimally compacted by vibration or tapping, a magnet was made from $SmCo_{3.5}Cu_{1.5}$ which contained only one magnetic fraction, and in addition only tin as a binder for mechanical cohesion. Seven grams powder of a fraction 37–53 $\mu$m. was intimately mixed with 3 g. tin powder of $<10$ $\mu$m. particle size and then magnetically aligned and compacted as described in Example 6. The sample had a density of 7.5 g./cm.$^3$,

$$B_r=32000 \text{ g., } _MH_c=5900 \text{ oe., } _BH_c=3000 \text{ oe.}$$

$$(BH)_{max}=2.3 \text{ mgoe}$$

A comparison of these numbers with those of the Examples 6 and 8 shows clearly which dramatic improvements can be obtained by the use of a second magnetic fraction (Example 8) and even more so through the use of three magnetically active portions (Example 6).

### EXAMPLE 13

Comparison of the magnets according to the invention with plastic bonded, pressed magnets made from Alnico alloys

It is commercial practice to bond chips of magnet alloys of the types AlNi and AlNiCo into magnets by means of synthetic resins. Such magnets are less brittle, cheaper, but also magnetically inferior to cast magnets of the same alloys. The preparation of such composite magnets is described in the German Pat. No. 656,966. In view of the similarities in the manufacturing techniques for these magnets, which are traded under the names Tromalit and Domalit, and one of the composite magnets described in this invention, the properties of these two magnet types shall be compared. (Tromalit and Domalit are trade names for organic resin-bonded Alnico magnets. Tromalit comprises 22% of Ni, 12% of Al, remainder Fe and is marketed by the German firm M. Bermann, Benzberg-Wulfshof near Cologne, Germany. Domalit is marketed by the same company.) The two types of composite magnets have quite comparable remanence values. Because of the high values of the intrinsic coercive force, however, which is attributable to the extraordinarily high crystal anisotropy of the magnetic alloy component, the new magnets described here have much higher $_BH_c$ and energy product values than the bonded Alnico powders. The quantitative data listed in the following table will prove this.

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## TABLE I

Comparison of the magnetic properties of the novel composite magnets with those of pressed magnets from AlNi and AlNiCo

|  | $B_r$ (g.) | $_BH_0$ (oe.) | $(BH)_{max}$ (mgoe.) |
|---|---|---|---|
| Magnet of Example No.: |  |  |  |
| 6 | 5,100 | 4,800 | 5.8 |
| 8 | 4,900 | 4,600 | 5.3 |
| 9 | 4,800 | 3,700 | 4.6 |
| 10 | 3,100 | 2,900 | 2.2 |
| 11 | 5,200 | 4,600 | 6.0 |
| Tradename: |  |  |  |
| Tromalit 600 | 3,500 | 600 | 0.63 |
| Tromalit 700 | 3,800 | 700 | 0.76 |
| Tromalit 800 | 4,200 | 800 | 0.97 |
| Tromalit 800 S | 5,000 | 800 | 1.23 |

NOTE.—The data for Tromalit are taken from the book by G. Hennig, "Permanent Magnet Technology," which was printed in the Francis-Verlag, Germany.

What is claimed is:

1. In a permanent magnet, wherein the magnet comprises compacted powders of magnetically anisotropic magnetic particles, the improvement which comprises that the powders are composed of at least two particle fractions of different average grain size, to wit
(a) a first fraction having an average grain size in the range of about 50–250 $\mu$m. and
(b) a second fraction having an average grain size in the range of about 5–50 $\mu$m., said first and second fractions having different chemical compositions
(c) said magnet also containing either a third fraction of such particles having an average grain size of about <15 $\mu$m. or an inorganic or organic binder, the weight ratio of $a:b:c$ being about 7:3:1, the ratio of the average grain sizes of the fractions $b:a$ and $c:b$ each being in the range of between 1:7 and 1:4 and the particle sizes of each fraction being substantially uniform.

2. The improvement of claim 1, wherein said particles are oriented and bonded.

3. The improvement of claim 1, wherein the particles of said fraction (a) essentially consist of precipitation hardened rare earth-cobalt alloys containing about 10–25 atomic percent of rare earths.

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4. The improvement of claim 1, wherein the particles of said fraction (b) essentially consist of precipitation hardened rare earth-cobalt alloys containing about 10–25 atomic percent rare earths or of a $RCo_5$ alloy, wherein R stands for rare earths.

5. The improvement of claim 4, wherein the $RCo_5$ alloy is at least one of $SmCo_5$, $PrCo_5$ or $YCo_5$.

6. The improvement of claim 1, wherein the magnet contains said third fraction (c), the particles of said fraction (c) essentially consisting of rare earth-cobalt alloys containing about 10–25 atomic percent of rare earths or of a permanent magnet compound or alloy which exhibits sufficient coercive force at particle sizes of <15 $\mu$m.

7. The improvement of claim 6, wherein said rare earth-cobalt alloys are precipitation hardened.

8. The improvement of claim 6, wherein said permanent magnet compound or alloy is barium ferrite or strontium ferrite.

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