

[Document Name] DESCRIPTION

[Title of the Invention]

Methods of producing composite compact for permanent magnet and producing permanent magnet blank

[Technical Field]

[0001]

The present invention relates to methods of producing a composite compact for a permanent magnet and producing a permanent magnet blank, more particularly, to methods of producing a composite compact for a permanent magnet and producing a permanent magnet blank using rare-earth metal materials.

[Background Art]

[0002]

Conventionally, for example, permanent magnets have been used for magnetic fields in some of electric motors, electric generators, etc. (for example, AC servomotors, synchronous motors, stepping motors, brushed DC motors and synchronous generators). With respect to the permanent magnets being used for these, a method is widely known in which rare-earth metal materials are subjected to plastic working to produce a permanent magnet blank and the permanent magnet blank is magnetized. For example, the method of producing a permanent magnet blank disclosed in Patent Document 1 is carried out as described below. A

material containing rare-earth and ferrous metals and boron is melted and cooled rapidly using the single-roll method to obtain a strip, the strip is crushed to obtain a powder having a predetermined grain diameter, and the powder is compacted by cold pressing, subjected to hot pressing so as to have a high density and further subjected to plastic working to produce a cup-shaped member having a predetermined shape (also referred to as a permanent magnet blank). Since the permanent magnet blank produced using the method described above has magnetic anisotropy, when it is magnetized as requested, it has a characteristic of being usable as a permanent magnet being excellent in magnetic properties.

[0003]

Patent Document 1: Japanese Patent Application Laid-Open Publication No. Hei 9-129463

[Disclosure of the Invention]

[Problem to be solved by the Invention]

[0004]

When a permanent magnet obtained by magnetizing a conventional permanent magnet blank as requested is exposed to high heat or subjected to an external demagnetization field or used in an environment in which these are combined (hereafter simply referred to as "exposed to high heat or the like" in this description), demagnetization due to the

heat or demagnetization due to the external magnetic field or demagnetization due to the combination of these (hereafter generally referred to as irreversible demagnetization) occurs in part of the permanent magnet in a short period, whereby there is a problem of deterioration in performance. Hence, generally, a countermeasure is taken to prevent irreversible demagnetization by enhancing the intrinsic coercive force of the permanent magnet.

To enhance the intrinsic coercive force of a rare-earth based permanent magnet (for example, a Nd-Fe-B permanent magnet or a Pr-Fe-B permanent magnet), the composition of the rare-earth elements is increased so that the rare-earth elements are rich, or part of Fe is substituted with Co, or the ratio of boron is increased, instead of using stoichiometric composition (for example, $\text{Nd}_2\text{Fe}_{14}\text{B}$ or $\text{Pr}_2\text{Fe}_{14}\text{B}$); however, these methods are limited in effect. Hence, part of Nd or Pr in the rare-earth elements is substituted with an element that is used to improve the intrinsic coercive force, such as Dy or Tb (hereafter simply referred to as "Dy or the like" in this description).

However, this method has the following problems. More specifically, the elements, such as Dy and Tb, are very expensive, and permanent magnets for applications that require high intrinsic coercive forces and use these elements in large amounts are high in cost. Furthermore,

although it is certain that the intrinsic coercive force is raised using the method of substitution with Dy or Tb, the method is defective because the residual magnetic flux density becomes lower. Furthermore, in applications requiring a large amount of magnetic flux, it is inevitable that the amount of use of magnets themselves is required to be increased to compensate for the low residual magnetic flux density, thereby resulting in a vicious circle of further increasing the cost of the permanent magnets. Moreover, the increase in the amount of the permanent magnets causes a problem of making apparatuses in which the permanent magnets are incorporated larger in size.

However, in recent years, requests for permanent magnets become increasingly severe year after year, and permanent magnets are required to satisfy all the requests for resistance against high temperature and for reduction in weight, size and cost. Hence, permanent magnets are increasingly requested so as not to cause irreversible demagnetization even when used in an environment in which they are exposed to high heat for example, so as to have reduced amounts of elements, such as Dy and Tb, and so that the magnets themselves are made compact.

[0005]

An object of the present invention is to provide methods of producing a composite compact for a permanent

magnet and producing a permanent magnet blank that can be used as a permanent magnet being excellent in magnetic properties when the permanent magnet blank formed of the composite compact is magnetized as a matter of course and that can be used for a long life period while the magnetic properties of the whole permanent magnet hardly deteriorate even when the permanent magnet is used in an environment in which the magnetic properties thereof are adversely affected, for example, even when the permanent magnet obtained by magnetizing the permanent magnet blank is exposed to high heat.

Another object is to provide methods of producing a composite compact for a permanent magnet and producing a permanent magnet blank capable of providing a permanent magnet blank having a high intrinsic coercive force even when the amount of use of Dy or the like in the whole permanent magnet blank is scarce.

Other objects and advantages will become easily apparent from the drawings and the following description in conjunction therewith.

[Effect of the Invention]

[0009]

As described above, in the present invention, since a composite compact E for a permanent magnet is formed by combining and integrating a high iH_c compact element A and

a high Br compact element B, each being formed of the above-mentioned magnetic powder, the permanent magnet blank F can be used as a permanent magnet being excellent in magnetic properties by magnetizing the permanent magnet blank F based on the above-mentioned composite compact for a permanent magnet in a way similar to that of the conventional method.

[0010]

In addition, in the present invention, since the composite compact E for a permanent magnet is formed by combining and integrating the high iHc compact element A that is formed of a magnetic powder Ma being high in intrinsic coercive force in comparison with the high Br compact element B and being low in residual magnetic flux density in comparison with the high Br compact element B and the high Br compact element B that is formed of a magnetic powder Mb being high in residual magnetic flux density in comparison with the high iHc compact element A and being low in intrinsic coercive force in comparison with the high iHc compact element A, when a permanent magnet obtained by magnetizing the above-mentioned permanent magnet blank F based on the above-mentioned composite compact for a permanent magnet is used in an environment in which the permanent magnet is subjected to heat or the like, the permanent magnet is characterized in

that the high iHc compact element side of the permanent magnet is hardly subjected to irreversible demagnetization by disposing the high iHc compact element side of the permanent magnet on the side affected by high heat or the like and by using the permanent magnet. Hence, the permanent magnet is effective during use in that the whole permanent magnet hardly deteriorates in magnetic properties and that the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

[0011]

Furthermore, in spite of the fact that the permanent magnet, hardly deteriorating in magnetic properties and being excellent in magnetic properties, can be used for a long life period as described above, since the composite compact E for a permanent magnet is formed by combining and integrating the high iHc compact element A formed of the magnetic powder Ma being high in intrinsic coercive force and the high Br compact element B formed of the magnetic powder Mb being high in residual magnetic flux density, the present invention can provide the composite compact E for a permanent magnet that is characterized so as to be hardly subjected to irreversible demagnetization and so as to be high in residual magnetic flux density.

[0012]

Moreover, since the high iH_c compact element A formed of the magnetic powder Ma being high in intrinsic coercive force may be used for part of the whole composite compact E for a permanent magnet, the composite compact is characterized in that expensive Dy or the like should only be used at the part. This means that the amount of use of expensive Dy or the like in the whole composite compact E for a permanent magnet is scarce, whereby an economic effect capable of providing the composite compact E for a permanent magnet being high in intrinsic coercive force at low cost is obtained.

[0013]

Still further, in the present invention, even when one or two or more intermediate compact elements C formed of magnetic powders Mc for the intermediate elements, the intrinsic coercive forces of which become lower sequentially in the direction from the above-mentioned high iH_c compact element A to the above-mentioned high Br compact element B, and the residual magnetic flux densities of which become lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iH_c compact element A, are disposed between the high iH_c compact element A formed of the magnetic powder Ma being high in intrinsic coercive force and the high Br compact element B formed of the magnetic powder Mb

being high in residual magnetic flux density, the amount of use of the above-mentioned expensive Dy or the like is reduced, whereby an economic effect capable of reducing the cost of the composite compact E for a permanent magnet is also obtained.

Other effects of the present invention will become easily apparent from the following description.

[Best Modes for carrying out the Invention]

[0014]

Embodiments according to the present invention will be described below referring to the drawings.

First, technical matters regarding the practice of the present invention will be described referring to FIGS. 1 to 12.

FIG. 1 is a figure illustrating a method of producing a permanent magnet blank F, showing an example in which the permanent magnet blank F having magnetic anisotropy is produced by sequentially subjecting a powder element 2 formed of a magnetic powder M to cold pressing, hot pressing and plastic working.

Numerical 2 in FIG. 1(a) designates an element obtained by filling the magnetic powder M into a cavity (not shown) in the die of a cold press and by forming the magnetic powder M into a shape adapted to the inner shape of the cavity. This is referred to as the "powder element" in

Claims, Description and Drawings in the present invention (hereafter referred to as the "present invention").

The magnetic powder M is produced using a known means; for example, the magnetic powder is obtained using a method in which molten metal obtained by melting a material containing rare-earth and ferrous metals and boron is jetted out onto a rotating roll to produce a rapid-quenched flaky ribbon and this rapid-quenched flaky ribbon is crushed to a powder having a required grain diameter.

The magnetic powder M is used as a generic name of a powder that is generally produced by using the above-mentioned rare-earth and ferrous metals and boron as materials. As the alloy composition of the magnetic powder M, various compositions satisfying requests are used. For example, Y and lanthanoid can be adopted as rare-earth metals; in particular, Nd, Pr, Dy and Tb or a mixture of these two or more kinds of metals can be adopted preferably.

Furthermore, Fe, Co and Ni can be adopted as ferrous metals; in particular, Fe and Co or a mixture of these two metals can be adopted preferably. When necessary, Ga may be added to improve plastic workability (prevention of cracking).

Numerals 3 in FIG. 1(b) designate a solid matter formed by compressing the powder element 2 using a known cold pressing means (for example, at room temperature and a

face pressure of 200 to 300 MPa) (this is herein referred to as the "solid element"). Numeral 4 in FIG. 1(c) designates a solid matter formed by compressing the solid element 3 using a known hot or warm pressing means (for example, in Ar atmosphere, at 700 to 900°C and a face pressure of 200 to 300 MPa) (this is herein referred to as the "high-density element"). Letter F in FIG. 1(d) designates a permanent magnet blank that is formed by subjecting the high-density element 4 to plastic working (for example, at 700 to 900°C, in the atmosphere, by carrying out extrusion) (FIG. 1(d) shows a single permanent magnet blank 60). The easy axes of magnetization 69 of the whole permanent magnet blank F are aligned along the thickness direction (the X-direction) thereof, and the permanent magnet blank has magnetic anisotropy. For example, the permanent magnet blank F is formed of the above-mentioned magnetic powder M as described above. A permanent magnet (not shown) is obtained by magnetizing the permanent magnet blank F using a known method.

[0015]

Next, an extrusion die that is used for the above-mentioned extrusion will be described.

FIG. 2 shows an extrusion die that is used for the method of producing the permanent magnet blank F, and a through hole 73, a tapered hole 75 and a uniformly sized

through hole 76 are formed in series in an extrusion die 71 mounted in a die holder 70. The high-density element 4 is extruded to the tapered hole 75 and the uniformly sized through hole 76 and formed into the plate-shaped permanent magnet blank F by pressing the high-density element 4 mounted in the through hole 73 using a press punch (not shown).

[0016]

As understandable from FIGS. 8(a) and 8(b), the above-mentioned extrusion die 71 is formed so that the high-density element 4 whose cross-section (extrusion cross-section) perpendicular to the extrusion direction (the direction of arrow 79) is rectangular is formed to form the permanent magnet blank F having a rectangular plate-shaped cross section, the width (in the Y-direction) W_1 of which is longer than the thickness (in the X-direction) T_1 thereof.

In other words, as also understandable from FIG. 2, the extrusion die 71 comprises an entry-side die 72 in which the above-mentioned through hole 73 extending in a predetermined length in the extrusion direction 79 is formed and a forming die 74 which is disposed on the exit side of the entry-side die 72 and in which the above-mentioned tapered hole 75 communicating with the through hole 73 is formed, and the above-mentioned uniformly sized

through hole 76 communicating with the tapered hole 75 is formed on the exit side 74b of the forming die 74.

[0017]

The through hole 73 formed in the above-mentioned entry-side die 72 is formed into a rectangle such that the dimensions of its cross-section perpendicular to the extrusion direction 79 in the X-direction and the Y-direction perpendicular thereto are nearly equal to the thickness T and the width W of the above-mentioned high-density element 4, respectively, and the high-density element 4 is mounted into the through hole 73 along its length direction (the Z-direction perpendicular to the X-direction and the Y-direction) while its thickness direction is aligned in the X-direction and its width direction is aligned in the Y-direction.

Furthermore, the uniformly sized through hole 76 formed on the exit side of the above-mentioned forming die 74 is formed into a rectangular shape such that the dimensions of its cross-section perpendicular to the extrusion direction 79 in the X-direction and the Y-direction perpendicular thereto are equal to the dimensions of the cross-section (the extrusion cross-section) perpendicular to the extrusion direction 79 of the permanent magnet blank F that is produced as shown in FIG. 8(b), that is, the thickness T1 and the width W1 thereof.

On the other hand, as shown in FIGS. 3 to 6, with respect to the tapered hole 75 formed in the above-mentioned forming die 74, the entrance 74a thereof at the tapered hole 75 is formed into a rectangle (the dimension in the X-direction is T and the dimension in the Y-direction is W) such that the dimensions in the X-direction and the Y-direction are equal to those in the corresponding directions of the through hole 73, and the exit side 74b of the tapered hole is formed into a rectangular shape (the dimension in the X-direction is T1 and the dimension in the Y-direction is W1) such that the dimensions in the X-direction and the Y-direction are equal to those in the corresponding directions of the uniformly sized through hole 76. In addition, the tapered hole 75 is tapered so as to be narrowed in the X-direction (see FIGS. 2(b) and 4) and expanded in the Y-direction (see FIGS. 2 and 3) from the entrance 74a to the exit side 74b.

More specifically, the high-density element 4 having a rectangular cross-section and extruded using the extrusion die 71 is narrowed (flattened) in the X-direction and expanded in the Y-direction as shown in FIG. 7, whereby the plate-shaped permanent magnet blank F having a rectangular cross section is formed. In other words, the X-direction is a direction in which the high-density element 4 is narrowed (flattened) at the time of extrusion, and the Y-

direction is a direction in which the high-density element 4 is expanded at the time of extrusion. In this case, the permanent magnet blank F is subjected to magnetic anisotropy in the X-direction, i.e., the maximum compression direction.

[0018]

The tapered hole 75 is set so that the shape of its curved face is inclined smoothly and so that smooth plastic working can be carried out for the high-density element 4. In addition, the above-mentioned entrance 74a of the forming die 74 is formed so as to have the same dimensions as those of the corresponding through hole 73 and to extend in a predetermined length in the axial direction, and the connection portion between the entrance 74a and the inclined face is formed so as to have a curved face having a predetermined radius of curvature so that smooth plastic working can be carried out for the high-density element 4. Furthermore, the exit side 74b of the tapered hole 75 is smoothly continued to the uniformly sized through hole 76 so that smooth plastic working is carried out for the high-density element 4.

[0019]

The respective dimensions of the above-mentioned high-density element 4 and the through hole 73, the tapered hole 75 and the uniformly sized through hole 76 of the extrusion

die 71 in the X-, Y- and Z-directions are set so that the strain ratio ϵ_2/ϵ_1 between the extrusion direction strain ϵ_1 of the permanent magnet blank F that is formed by extruding the high-density element 4 and the strain ϵ_2 in the Y-direction is in the range of 0.2 to 3.5, preferably 0.4 to 1.6. In other words, when the plate-shaped permanent magnet blank F having the thickness T1, the width W1 and the length L1 is formed from the high-density element 4 having the rectangular cross section and having the thickness T, the width W and the length L as described above, the dimensions of the high-density element 4, the through hole 73, the tapered hole 75 and the uniformly sized through hole 76 in the respective directions are set so that the relationship represented by the following formula 1 is established.

$$\epsilon_2/\epsilon_1 = \ln(W1/W)/\ln(L1/L) = 0.2 \text{ to } 3.5 \quad \dots \text{ (formula 1)}$$

wherein ln denotes logarithm natural.

[0020]

By setting the strain ratio ϵ_2/ϵ_1 within the range represented by the formula 1, the magnetic properties, such as the residual magnetic flux density (Br), the IH curve's intrinsic coercive force (iHc) and the maximum energy product ((BH)max), of the permanent magnet obtained by extrusion are improved to levels equivalent or superior to the magnetic properties of a permanent magnet produced by

upsetting. Moreover, the magnetic properties of the permanent magnet to be obtained are improved further by setting the strain ratio ϵ_2/ϵ_1 to the range of 0.4 to 1.6.

More specifically, the magnetic anisotropy in the X-direction is enhanced and high magnetic properties are obtained by making the strain ϵ_1 applied to the permanent magnet blank F in the extrusion direction by plastic working equal to the strain ϵ_2 in the Y-direction. Hence, the magnetic properties are improved to the highest degree by setting the strain ratio ϵ_2/ϵ_1 to 1. When the strain ratio ϵ_2/ϵ_1 is outside the above-mentioned range, the magnetic anisotropy in the X-direction is low, and high magnetic properties are hardly obtained.

[0021]

[Experiment 1]

A magnetic alloy containing 29.5 mass% of Nd, 5 mass% of Co, 0.9 mass% of B, 0.6 mass% of Ga and the remainder being substantially Fe was produced by melting and cooled rapidly using the single-roll method to obtain a magnetic strip having a thickness of 25 μm and an average crystal grain diameter of 0.1 μm or less. Furthermore, this magnetic strip was crushed to obtain a magnetic powder M having a length of 200 μm or less. A powder element 2 formed of 130.8 g of the magnetic powder M was compacted by cold pressing at room temperature and a face pressure of

200 MPa to obtain a solid element 3 having a thickness T of 36 mm, a width W of 19 mm and a length L of 36 mm.

Moreover, hot pressing was carried out in Ar atmosphere at a temperature of 800°C and a face pressure of 200 MPa to produce a high-density element 4 having a rectangular cross-section and having a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm. The average crystal grain diameter of the high-density element 4 was 0.1 μm at this time. The ratio of the bulk density to the real density thereof was 0.999. In Experiment 1, the effect of the strain ratio ϵ_2/ϵ_1 was examined by changing the strain ratio ϵ_2/ϵ_1 of the permanent magnet blank F that was formed by extrusion from the high-density element 4 having a fixed shape.

[0022]

In other words, as shown in Tables 1 and 2, the above-mentioned high-density element 4 was extruded using the extrusion die 71 in which the through hole 73, the tapered hole 75 and the uniformly sized through hole 76 were designed so as to obtain respective permanent magnet blanks F: Example 1 in which the thickness T_1 after extrusion is 8 mm and the strain ratio ϵ_2/ϵ_1 is 0.1, Example 2 in which the strain ratio ϵ_2/ϵ_1 is 0.2, Example 3 in which the strain ratio ϵ_2/ϵ_1 is 0.4, Example 4 in which the strain ratio ϵ_2/ϵ_1 is 0.8, Comparative Example 1 in which the strain ratio

ϵ_2/ϵ_1 is 1.0, Example 5 in which the strain ratio ϵ_2/ϵ_1 is 1.6, Example 6 in which the strain ratio ϵ_2/ϵ_1 is 2.0, Example 7 in which the strain ratio ϵ_2/ϵ_1 is 3.5, and Example 8 in which the strain ratio ϵ_2/ϵ_1 is 4.0. The residual magnetic flux density (B_r), the IH curve's intrinsic coercive force (iH_c) and the maximum energy product $((BH)_{max})$ of each of permanent magnets obtained by magnetizing the obtained permanent magnet blanks F according to the respective examples in the same conditions were measured in the X-direction, and the results were shown in Table 1. Furthermore, Table 2 shows the dimensions of the high-density elements 4 and the obtained permanent magnet blanks F according to Examples 1 to 8 and Comparative Example 1.

[0023]

The temperature of the high-density element 4 and the extrusion die 71 during extrusion was 800°C, and an 80-ton hydraulic press was used as a processing machine.

In addition, magnetic measurement test samples, having a width of 8 mm, a length of 8 mm and a thickness of 8 mm, taken from the central portions in the width and length directions of the permanent magnet blanks F and magnetized in a magnetic field of 3.2 MA/m, were used for the specific measurements of the magnetic properties of the respective permanent magnet blanks F according to Examples 1 to 8 and Comparative Example 1. Furthermore, the magnetic

properties of the respective magnetic measurement test samples having been saturatedly magnetized by the above-mentioned magnetization were measured using a BH tracer. When the tissue of the crystal grains of the magnetic measurement test sample according to Comparative Example 1 was observed, its shape was flat and measured 0.1 μm in the X-direction and 0.5 μm in the Y-direction on the average.

[0024]

[Table 1]

	Strain ratio $\varepsilon_2/\varepsilon_1$	Br T	iHc MA/m	(BH)max KJ/m ³
Example 1	0.1	1.08	1.28	235
Example 2	0.2	1.14	1.22	260
Example 3	0.4	1.35	1.21	360
Example 4	0.8	1.41	1.22	392
Comparative Example 1	1.0	1.47	1.22	428
Example 5	1.6	1.44	1.20	401
Example 6	2.0	1.20	1.23	285
Example 7	3.5	1.15	1.25	264
Example 8	4.0	1.12	1.28	250
Comparative Example 2	1.0	1.36	1.85	372
Example 9	1.0	1.46	1.21	422
Example 10	1.0	1.43	1.22	406

[0025]

[Table 2]

	High-density element 4			Permanent magnet blank F			ϵ_2/ϵ_1
	Thickness T (mm)	Width W (mm)	Length L (mm)	Thickness T1 (mm)	Width W1 (mm)	Length L1 (mm)	
Example 1	36	19	25	8	21.8	98.1	0.1
Example 2	36	19	25	8	24.4	87.5	0.2
Example 3	36	19	25	8	29.2	73.2	0.4
Example 4	36	19	25	8	37	57.8	0.8
Comparative Example 1	36	19	25	8	40	53.4	1.0
Example 5	36	19	25	8	48	44.5	1.6
Example 6	36	19	25	8	52	41.1	2.0
Example 7	36	19	25	8	61.2	34.9	3.5
Example 8	36	19	25	8	63.3	33.8	4.0
Comparative Example 2	36	19	25	8	40	53.4	1.0

[0026]

[Experiment 2]

A magnetic powder M was obtained in the same conditions as those of the above-mentioned Experiment 1 using a magnetic alloy containing 26.8 mass% of Nd, 0.1 mass% of Pr, 3.6 mass% of Dy, 6 mass% of Co, 0.89 mass% of B, 0.57 mass% of Ga and the remainder being substantially Fe. Then, a powder element 2, a solid element 3 and a high-density element 4 were produced sequentially. The magnetic properties of a permanent magnet blank F formed by extrusion as in the case of the above-mentioned Comparative Example 1 so as to have a thickness T1 of 8 mm and a strain ratio ϵ_2/ϵ_1 of 1.0 after extrusion from the produced high-density element 4 having the same dimensions as those of

Comparative Example 1 were shown as Comparative Example 2 in Table 1. Furthermore, the dimensions of the high-density element 4 and the obtained permanent magnet blank F according to Comparative Example 2 were shown in Table 2. The extrusion conditions and the specific method of measuring the magnetic properties were the same as those in Experiment 1.

[0027]

Next, in FIGS. 1 to 8, extrusion was taken as an example of plastic working for providing the permanent magnet blank F with magnetic anisotropy and illustrated. However, as is commonly known, processes such as upsetting and rolling are used in addition to the above-mentioned extrusion as plastic working for providing the permanent magnet blank with magnetic anisotropy, and such processes should only be selectively used as necessary.

Furthermore, in FIGS. 1 to 8, the forming of the permanent magnet blank F by subjecting the single high-density element 4 to plastic working was described above. However, plastic working similar to the above-mentioned plastic working and other known plastic working can be applied to other composite compacts E identical with the above-mentioned high-density element 4, that is, the composite compacts E shown in FIGS. 13 and 33, and the permanent magnet blanks F respectively corresponding

thereto can be formed.

[0028]

Next, FIGS. 9 and 10 will be described, showing examples different from the high-density element 4, the permanent magnet blank F and the extrusion die 71 shown in FIGS. 1 to 8 in the shapes of the high-density element 4 and the permanent magnet blank F and the shapes of the through hole 73, the tapered hole 75, the uniformly sized through hole 76 and the forming die 74 of the extrusion die.

Although the production of the plate-shaped permanent magnet blank F from the high-density element 4 having a rectangular cross section was described above referring to FIGS. 1 to 8, the plate-shaped permanent magnet blank F (permanent magnet blank 60a) may be produced from a high-density element 4a having a cylindrical shape as shown in FIGS. 9(a) and 9(b). In other words, when the plate-shaped permanent magnet blank 60a having a thickness T_1 , a width W_1 and a length L_1 is extruded from the cylinder-shaped high-density element 4a having diameters D (in the X-direction and Y-direction) and the length L (in the Z-direction), the dimensions of the through hole, the tapered hole and the uniformly sized through hole are set so that the strain ratio $\epsilon_2/\epsilon_1 = \ln(W_1/W)/\ln(L_1/L)$ is in the range of 0.2 to 3.5, preferably 0.4 to 1.6, whereby the working-effect similar to that described above is obtained.

In a forming die 84 for producing the permanent magnet blank 60a shown in FIG. 9, as understandable from FIG. 10, the entrance 84a of the tapered hole 85 should only be formed into a circular shape having the same diameter as that of the high-density element 4a, and the exit side 84b of the tapered hole 85 and the uniformly sized through hole 86 should only be formed into a rectangular shape having a dimension T1 in the X-direction and a dimension W1 in the Y-direction, the dimensions being equal to those of the permanent magnet blank 60a.

[0029]

[Experiment 3]

The magnetic properties of the permanent magnet blank 60a in the X-direction are shown in Table 1 as Example 9, the permanent magnet blank being extruded from the cylinder-shaped high-density element 4a having a diameter D of 14.5 mm, a length L of 22.5 mm and produced in the same conditions as those in Experiment 1 using a magnetic alloy having the same composition as that of the above-mentioned Experiment 1 so that the thickness T1 after extrusion is 3 mm and so that the strain ratio ϵ_2/ϵ_1 is 1.0. Furthermore, Table 3 shows the dimensions of the high-density element 4a and the obtained permanent magnet blank 60a according to Example 9. In addition, a magnetic measurement test sample, having a width of 8 mm, a length of 8 mm and a thickness of

3 mm, taken from the central portions in the width and length directions of the permanent magnet blank F and magnetized in a magnetic field of 3.2 MA/m, was used for specific measurements of the magnetic properties of the respective permanent magnet blank F according to Example 9, and the measurements were carried out using a BH tracer.

[0030]

[Table 3]

	High-density element 4		Permanent magnet blank 60a			ϵ_2/ϵ_1
	Diameter D (mm)	Length L (mm)	Thickness T1 (mm)	Width W1 (mm)	Length L1 (mm)	
Example 9	14.5	22.5	3	28.3	43.8	1.0

[0031]

Next, an example shown in FIG. 11 and different from the high-density element 4 and the permanent magnet blank F shown in FIGS. 1 to 8 in the shapes of the high-density element 4 and the permanent magnet blank F will be described.

As shown in FIGS. 11(a) and 11(b), extrusion is carried out to form a permanent magnet blank F (permanent magnet blank 60b) having an arc-shaped cross section and having a thickness (in the X-direction) T1, an arc length (in the Y-direction) W1 on the outer circumferential side, an arc length (in the Y-direction) W2 on the inner circumferential side and a length (in the Z-direction) L1

from the high-density element 4b having a rectangular cross section and having a thickness (in the X-direction) T, a width (in the Y-direction) W and a length (in the Z-direction) L.

When the extrusion is carried out, the dimensions of the through hole 73, the tapered hole 75 and the uniformly sized through hole 76 of the extrusion die should only be set so that the strain ratio $\epsilon_2/\epsilon_1 = \ln((W1 + W2)/2)/W) / \ln(L1/L)$ is in the range of 0.2 to 3.5, preferably 0.4 to 1.6.

With this setting, the working-effect similar to that described above referring to FIGS. 1 to 8 is obtained. The magnetic anisotropy direction of the permanent magnet blank 60b shown in FIG. 11 is the radial direction perpendicular to its arc.

[0032]

[Experiment 4]

The magnetic properties of the permanent magnet blank 60b are shown in Table 1 as Example 10, the permanent magnet blank being extruded from the high-density element 4b having a rectangular cross section and having a thickness T of 24 mm, a width W of 23 mm and a length L of 25 mm and produced in the same conditions as those in Experiment 1 using a magnetic alloy having the same composition as that of the above-mentioned Experiment 1 so

that the thickness T_1 is 8 mm, the arc length $((W_1 + W_2)/2)$ is 40 mm and the radius R_1 of the arc is 40 mm and so that the strain ratio ϵ_2/ϵ_1 is 1.0.

Furthermore, Table 4 shows the dimensions of the high-density element 4b and the obtained permanent magnet blank 60b according to Example 10. In addition, a magnetic measurement test sample, having a width of 8 mm and a length of 8 mm, taken from the central portions in the width and length directions of the permanent magnet blank 60b, trimmed approximately 0.5 mm at each of both ends of the arc portions in the thickness direction so as to have a thickness of 7 mm, and magnetized in a magnetic field of 3.2 MA/m, was used for specific measurements of the magnetic properties of the permanent magnet blank 60b according to Example 10, and the measurements were carried out using a BH tracer.

[0033]

[Table 4]

	High-density element 4			Permanent magnet blank 60b					ϵ_2/ϵ_1
	Thickness T (mm)	Width W (mm)	Length L (mm)	Thickness T ₁ (mm)	Arc Length W ₁ (mm)	Arc Length W ₂ (mm)	Length L ₁ (mm)	Arc Radius R ₁ (mm)	
Example 10	24	23	25	8	44.4	35.6	43.1	40	1.0

[0034]

According to the experimental results shown in Table 1,

it is verified that the magnetic properties are improved by setting the strain ratio ϵ_2/ϵ_1 in the range of $0.2 \leq \epsilon_2/\epsilon_1 = 3.5$ and further improved by setting the strain ratio ϵ_2/ϵ_1 in the range of $0.4 \leq \epsilon_2/\epsilon_1 = 1.6$. In addition, it is verified that the magnetic properties are improved to the highest degree as the strain ratio ϵ_2/ϵ_1 becomes close to 1. Furthermore, the permanent magnet blanks F according to Comparative Examples 1 and 2 and Examples 1 to 10 are all excellent in external appearance and not required to be trimmed except approximately 2 mm at each of the leading and trailing ends in the length direction. Moreover, according to the results of penetrant and eddy-current flaw detection tests, surface and internal cracks were not observed. In other words, with the present invention, it is verified that permanent magnets having high magnetic properties can be produced by carrying out extrusion that is excellent in productivity, yield and production cost.

[0035]

Next, an example shown in FIG. 12 and different from the high-density element 4 and the permanent magnet blank F shown in FIGS. 1 to 8 in the shapes of the high-density element 4 and the permanent magnet blank F will be described.

1. A permanent magnet blank F (permanent magnet blank 60c having a semicylindrical cross section) having a

semicylindrical cross section and having a maximum thickness (in the X-direction) T1, an arc length on the arc side (in the Y-direction) W1, a width (in the Y-direction) W2 on the straight side (in the Y-direction) and a length (in the Z-direction) L1 shown in FIG. 12(b) or a permanent magnet blank F (permanent magnet blank 60d having a crescent cross section) having a crescent cross section and having a maximum thickness (in the X-direction) T1, an arc length (in the Y-direction) W1 on the outer circumferential side, an arc length (in the Y-direction) W2 on the inner circumferential side and a length (in the Z-direction) L1 shown in FIG. 12(c) may be produced from a high-density element 4c having an oval cross section and having a minor axis diameter D1, a major axis diameter D2 and a length (in the Z-direction) L shown in FIG. 12(a).

In this case, the working-effect similar to that described above referring to FIGS. 1 to 8 is obtained by setting the dimensions of the through hole 73, the tapered hole 75 and the uniformly sized through hole 76 of the extrusion die 71 so that the strain ratio $\epsilon_2/\epsilon_1 = \ln((W1 + W2)/2)/D2)/\ln(L1/L)$ is in the range of 0.2 to 3.5, preferably 0.4 to 1.6.

When the permanent magnet blank 60c having a semicylindrical cross section or the permanent magnet blank 60d having a crescent cross section is produced from the

high-density element 4c having an oval cross section, the X- and Y-directions of the high-density element 4c are determined by the relationship among the thickness T1 and the widths (arc lengths) W1 and W2 of the permanent magnet blanks 60c and 60d to be obtained.

More specifically, there are cases in which the minor axis diameter D1 is oriented in the X-direction and the major axis diameter is oriented in the Y-direction, and the minor axis diameter D1 is oriented in the Y-direction and the major axis diameter is oriented in the X-direction. Since this relationship is similarly applicable when an oval shape is formed into a rectangular shape, specific examples thereof are shown in Table 5.

[0036]

[Table 5]

	High-density element 4			Permanent magnet blank 60c, 60d			e_2/e_1
	D1 (mm) X-direction	D2 (mm) Y-direction	Length L (mm)	Thickness T1 (mm)	Width W1 (mm)	Length L1 (mm)	
True circle	14.5	14.5	22.5	3	28.3	43.8	1.0
Minor axis in X-direction	14.5	16	22.5	3	31.2	43.8	1.0
Major axis in X-direction	14.5	13	22.5	3	25.4	43.8	1.0

2. The cross-section shapes of the preform and the permanent magnet may be shapes other than those described in the respective examples. Furthermore, the combinations of the cross sections of the preform and the permanent

magnet may be combinations other than those of the respective embodiments.

3. Although the entrance of the tapered hole 75 in the forming die 74 described above referring to FIGS. 2 to 7 is formed so as to have a portion having a shape identical with that of the through hole 73 and extending in a predetermined length, the tapered hole 75 may be formed such that the taper is directly connected to the end of the through hole 73.

[0037]

Next, embodiments shown in FIGS. 13 to 42 according to the present invention will be described.

[Embodiment 1]

[0038]

As shown in FIG. 13, in the method of producing a permanent magnet blank F, a composite compact E for a permanent magnet is formed by combining and integrating a high iH_c compact element A that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high B_r compact element B and being low in residual magnetic flux density in comparison with the high B_r compact element B and the high B_r compact element B that is formed of a magnetic powder being high in residual magnetic flux density in comparison with the high iH_c compact element A and being low in intrinsic coercive force in

comparison with the high iHc compact element A, and the above-mentioned composite compact E is subjected to plastic working, thereby being provided with magnetic anisotropy.

[0039]

This matter will be described in more detail. FIG. 13 is a figure for describing the method of producing the permanent magnet blank F; as sequentially shown in FIGS. 13(a) to 13(d), an example is described in which the high iHc compact element A and the high Br compact element B are formed individually, and they are combined and integrated to form a composite compact E for a permanent magnet (this is also referred to as the "composite compact E" in the present invention), and the composite compact E is subjected to plastic working to form a permanent magnet blank F.

In the high iHc compact element A shown in the upper portions of FIGS. 13(a), 13(b) and 13(c), numeral 6 designates a high iHc powder element that is formed by filling a magnetic powder into the cavity (not shown) in a cold press. The above-mentioned magnetic powder should only be produced using a known means in a way similar to that described earlier for the above-mentioned magnetic powder M referring to FIG. 1. The material properties of the magnetic powder should only be those being high in intrinsic coercive force and being low in residual magnetic

flux density in comparison with the magnetic powder for forming the high Br compact element B. For example, the magnetic powder M used in the above-mentioned Experiment 2 may be used, or it may also be possible to use a magnetic powder in which the composition of the magnetic alloy is changed or the Dy or the like is increased or decreased depending on requests with respect to irreversible demagnetization, large/small size, cost, etc. In the present invention, these powders are also referred to as the "magnetic powder Ma"). The magnetic powder Ma has conditions that the residual magnetic flux density thereof is lower than the residual magnetic flux density of the high Br compact element B and that the intrinsic coercive force thereof is higher than the intrinsic coercive force of the high Br compact element B. The magnetic powder being used for the high iHc compact element A may be wholly formed of the magnetic powder Ma or may be formed of a mixture in which the magnetic powder Ma and the magnetic powder Mb described later are mixed appropriately in the ranges of the above-mentioned conditions. Numeral 7 designates a high iHc solid element formed by pressing the high iHc powder element using a cold pressing means, and numeral 8 designates a high iHc high-density element produced by pressing the high iHc solid element 7 using a hot or warm pressing means. Known means should only be

used as the cold, hot or warm pressing means; for example, the cold, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

[0040]

Next, in the high Br compact element B shown in the lower portions of FIGS. 13(a), 13(b) and 13(c), numeral 11 designates a high Br powder element that is formed by filling the magnetic powder Mb into the cavity (not shown) in a cold press. The magnetic powder Mb should only be produced using a known means in a way similar to that described earlier for the above-mentioned magnetic powder M referring to FIG. 1. The material properties of the magnetic powder Mb should only be those being low in intrinsic coercive force and being high in residual magnetic flux density in comparison with the magnetic powder Ma for forming the high iHc compact element A. For example, the magnetic powder M (Br: 1.47 T, iHc: 1.22 MA/m) used in the above-mentioned Experiment 1 may be used, or it may also be possible to use a magnetic powder in which the composition of the magnetic alloy is changed or the Dy or the like is added depending on requests with respect to irreversible demagnetization, large/small size, cost, etc. In the present invention, these powders are also referred to as the "magnetic powder Mb"). The magnetic powder being used for the high Br compact element B may be wholly formed

of the above-mentioned magnetic powder Mb or may be formed of a mixture in which the magnetic powder Mb and the magnetic powder Ma are mixed appropriately in the ranges of the above-mentioned conditions.

Numeral 12 designates a high Br solid element formed by pressing the high Br powder element 11 using a cold pressing means, and numeral 13 designates a high Br high-density element produced by pressing the high Br solid element 12 using a hot or warm pressing means. As the cold, hot or warm pressing means, known means should only be used; for example, cold, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

[0041]

The external dimensions of the high iHc high-density element 8 and the high Br high-density element 13 should only be dimensions such that a composite compact E having predetermined external dimensions is formed when the two elements are combined and integrated. For example, the high iHc high-density element 8 should only have a thickness T2 of 18 mm, a width W2 of 19 mm and a length L2 of 25 mm; and the high Br high-density element 13 should only have a thickness T2 of 18 mm, a width W2 of 19 mm and a length L2 of 25 mm. Hence, the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of

25 mm.

[0042]

Next, the high iHc high-density element 8 (the high iHc high-density compact element A) and the high Br high-density element 13 (the high Br compact element B), produced individually, are combined using an arbitrary known means as shown in FIG. 13(c2). This combined state should only be held with a light force so that the elements are not detached (separated) until they are inserted into a die that is used for the next-stage plastic working (for example, the respective elements should only be held with a robot hand or the like until just before they are inserted into a die). The composite compact E in the above-mentioned combined state can be integrated using an arbitrary known means for carrying out integration, such as a known pressing means for carrying out integration. In addition, at this time, the composite compact may also be formed into such arbitrary external shapes as shown in FIGS. 20 to 22 described later to meet requests.

[0043]

Next, the composite compact E (two-element composite compact 51) in the combined state shown in FIG. 13(c2) is subjected to plastic working so as to be provided with magnetic anisotropy, and the permanent magnet blank F (two-element permanent magnet blank 61) shown in FIG. 13(d) is

formed. The above-mentioned various plastic working processes should only be used as plastic working processes; for example, in a way similar to that described above referring to FIGS. 1 to 8, extrusion should only be carried out for forming using the extrusion die 71. Since the composite compact E is heated to high temperature by plastic working, its phases rich in rare-earth elements are melted and integrated spontaneously.

Next, in the extrusion direction at the time of the above-mentioned extrusion, when the permanent magnet blank F is used such that one side of the magnetic pole is used as a side having a high intrinsic coercive force and such that the other side is used as a side having a high residual magnetic flux density, for example, extrusion should be carried out in the direction (the direction indicated by arrow 79) parallel with the alignment face 57 of the high Br compact element B and the high iHc compact element A of the above-mentioned composite compact E; and in the direction of flattening the above-mentioned composite compact E, the composite compact E should be flattened (narrowed) in the direction (in the X-direction) perpendicular to the above-mentioned alignment face 57 so that the easy axes of magnetization 69 of the permanent magnet blank F are aligned in the direction (the X-direction) perpendicular to the above-mentioned alignment

face 57.

With the extrusion carried out described above, the object of the present invention "the high iHc compact element A is positioned on one side of the magnetic pole and the high Br compact element B is positioned on the other side of the magnetic pole" is attained. This is applicable similarly when the permanent magnet blank F is formed by subjecting the respective composite compacts E shown in FIGS. 15, 16, 24, 26, 28, 30 and 33 to plastic working.

When the above-mentioned permanent magnet blank F is magnetized and used as a permanent magnet, the permanent magnet blank F is characterized in that one side of the magnetic pole can be used as a side having a high intrinsic coercive force and that the other side can be used as a side having a high residual magnetic flux density.

In the permanent magnet blank F shown in FIG. 13(d), numeral 67 designates the side of the high iHc compact element A, numeral 68 designates the side of the high Br compact element B, and numeral 69 designates the direction of the easy axes of magnetization 69.

Although the external dimensions of the permanent magnet blank F are different depending on the plastic working carried out for the composite compact E, when extrusion similar to that for Comparative Example 1 in the

above-mentioned Experiment 1 is carried out for example, and when the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm, the permanent magnet blank F has a thickness T1 of 8 mm, a width W1 of 40 mm and a length L1 of 53.4 mm.

[0044]

The two-layer permanent magnet blank F produced as described above has magnetic anisotropy since the easy axes of magnetization 69 of the whole are aligned. Hence, when the permanent magnet blank F is magnetized, it can be used as a permanent magnet being excellent in magnetic properties. The residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet are shown in Table 6. Furthermore, the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of the permanent magnet is shown in FIG. 14.

[0045]

[Table 6]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.36	1.85	3.6
High Br compact element B side(2nd layer)	1.47	1.22	0
Permanent magnet	1.425	—	1.8

[0046]

As shown in Table 6 and FIG. 14, the iHc compact element A side of the permanent magnet is very high in intrinsic coercive force (1.85 MA/m) since the Dy content rate is 3.6 mass%. Hence, when the permanent magnet is used in an environment in which it is exposed to heat, by disposing and using the iHc compact element A side of the permanent magnet on the side subjected to the effect of the heat, the magnetic properties of the whole permanent magnet hardly deteriorate since the iHc compact element A side of the permanent magnet is characterized so as to be hardly subjected to irreversible demagnetization, whereby the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

In addition, as shown in Table 6, since the amount of use of Dy in the whole permanent magnet is 1.8 mass% on the average of the iHc compact element A and the high Br compact element B, it is characterized in that a permanent magnet capable of delivering a high intrinsic coercive force described above can be obtained using such a small amount of the expensive Dy.

As the intrinsic coercive force on the iHc compact element A side and the intrinsic coercive force on the high Br compact element B side of the permanent magnet, 1.85 MA/m and 1.22 MA/m are described as examples, respectively.

However, these are examples in a permanent magnet obtained

by magnetizing the permanent magnet blank F shown in FIG. 13(d). Generally speaking, the required intrinsic coercive force is different depending on the place of use of the permanent magnet for magnetizing the permanent magnet blank F, the temperature condition, the magnitude of the external magnetic field, and the dimensions of the magnet. For this reason, the intrinsic coercive forces should only be set, for example, by changing the respective compositions of the magnetic powders Ma and Mb on the high iHc compact element A side and the high Br compact element B side as necessary.

[0047]

Next, an example of the process of combining and integrating the high iHc compact element A and the high Br compact element B, different from the process for forming the composite compact E shown in FIGS. 13(a) to 13(c2) in the integrating process, will be described referring to FIGS. 15 and 16.

[Embodiment 2]

[0048]

As sequentially shown in FIGS. 15(a) to 15(d), an example is described in which the high iHc compact element A and the high Br compact element B are formed individually, they are combined and integrated at the time shown in FIG. 15(b2) to form a composite solid element 10, the composite solid element 10 is subjected to hot pressing to form a

composite compact E, and the composite compact E is further subjected to plastic working to form a permanent magnet blank F.

In the respective figures in the present invention, the portions identical or equal to those in other figures with respect to functions, properties, means or characteristics are designated by the same numerals as those used in other figures, and the explanations for the functions, properties, means or characteristics are incorporated by reference. Hence, overlapping explanations are omitted.

[0049]

In FIG. 15(b2), numeral 10 designates a composite solid element obtained by combining and integrating the high iH_c solid element 7 (the high iH_c compact element A) and the high B_r solid element 12 (the high B_r compact element B). This combined state should only be held with a light force in a way similar to that described referring to FIG. 13(c2) so that the elements are not detached (separated) until they are inserted into a die that is used for the next-stage hot or warm pressing. This composite solid element 10 is integrated using a hot or warm pressing means to form a composite compact E (two-element composite compact 51) shown in FIG. 15(c). Since the composite solid element 10 is heated to high temperature by hot or warm

pressing, its phases rich in rare-earth elements are melted and integrated spontaneously. Known means should only be used as the hot or warm pressing means; for example, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

[0050]

Next, the composite compact E shown in FIG. 15(c) is subjected to plastic working to form a permanent magnet blank F shown in FIG. 15(d). As plastic working, the above-mentioned various plastic working should only be used.

The working-effect similar to that in Embodiment 1 is obtained from the permanent magnet blank F (two-element composite compact 61) produced as described above.

[Embodiment 3]

[0051]

Next, in FIG. 16, an example is described in which the magnetic powder Ma and the magnetic powder Mb described referring to FIG. 13 at the time shown in FIG. 16(a) are combined and integrated inside a cavity to form a composite powder element 9, the composite powder element 9 is subjected to cold pressing and hot pressing to sequentially form a composite solid element 10 and a composite compact E, and the composite compact E is further subjected to plastic working to form a permanent magnet blank F.

[0052]

The high iHc powder element 6 and the high Br powder element 11 constituting the composite powder element 9 shown in FIG. 16(a) are powder elements formed by combining (by filling into the cavity of a die in a parallel state) and integrating the magnetic powder Ma and the magnetic powder Mb. When the magnetic powders Ma and the magnetic powder Mb are filled into the cavity of the die, the spaces to be filled with the magnetic powders Ma and the magnetic powder Mb should only be partitioned beforehand using an arbitrary partitioning jig inside the cavity. Furthermore, the surface of the above-mentioned jig should be coated beforehand with Li stearate. With this coating, powder lifting is prevented when the jig is pulled out after the filling of the magnetic powders Ma and the magnetic powder Mb.

[0053]

Numerical 10 in FIG. 16(b) designates a composite solid element formed by pressing the composite powder element 9 using a cold pressing means, the element being formed by combining and integrating the high iHc compact element A and the high Br compact element B. The composite solid element 10 is pressed using a hot or warm pressing means to form a composite compact E (two-element composite compact 51) shown in FIG. 16(c). Known means should only be used as the cold, hot or warm pressing means; for example, the

cold, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

Next, the composite compact E shown in FIG. 16(c) is subjected to plastic working to form a permanent magnet blank F shown in FIG. 16(d). As plastic working, the above-mentioned various plastic working should only be used.

The working-effect similar to that in Embodiment 1 is obtained from the permanent magnet blank F (two-element composite compact 61) produced as described above.

[Embodiment 4]

[0054]

Next, FIG. 17 showing an example is explained in which the direction of flattening a composite compact E at the time of extrusion is a direction that is parallel with the alignment face 57 of the composite compact E and perpendicular (in the Y-direction) to the extrusion direction 79, thereby being different from the direction of flattening the composite compact E shown in FIG. 13(c2).

The example shown in FIG. 17 is an example for providing the following matter, an object of the present invention, that is, an example for providing a method of producing a permanent magnet blank F in which the easy axes of magnetization 69 of the permanent magnet blank F are aligned in the direction parallel with the above-mentioned alignment face 57 and perpendicular to the extrusion

direction 79.

[0055]

As sequentially shown in FIGS. 17(a) to 17(c), the high iHc compact element A and the high Br compact element B are formed individually. Next, the high iHc high-density compact element A (high iHc high-density element 8) and the high Br compact element B (high Br high-density element 13) shown in FIG. 17(c) and produced individually are combined and integrated in the width direction (in the Y-direction) as shown in FIG. 17(c2) to produced a composite compact E (two-element composite compact 51).

The external dimensions of the high iHc high-density element 8 and the high Br high-density element 13 shown in FIG. 17(c) should only be dimensions such that a composite compact E having predetermined external dimensions is formed when the two elements are combined and integrated. For example, the high iHc high-density element 8 should only have a thickness T2 of 36 mm, a width W2 of 9.5 mm and a length L2 of 25 mm; and the high Br high-density element 13 should only have a thickness T2 of 36 mm, a width W2 of 9.5 mm and a length L2 of 25 mm. Hence, the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm.

[0056]

Next, the composite compact E shown in FIG. 17(c2) is

subjected to plastic working to form a permanent magnet blank F shown in FIG. 17(d). As plastic working, the above-mentioned various plastic working should only be used.

Furthermore, unlike the case shown in FIG. 13, the extrusion direction at the time of the above-mentioned extrusion is a direction (the direction indicated by arrow 79) parallel with the alignment face 57 of the high Br compact element B and the high iHc compact element A in the above-mentioned composite compact E; the direction of flattening (narrowing) the above-mentioned composite compact E may be a direction that is parallel with the above-mentioned alignment face 57 and perpendicular to the above-mentioned extrusion direction; and the easy axes of magnetization of the permanent magnet blank F may be oriented in a direction parallel with the above-mentioned alignment face and perpendicular to the above-mentioned extrusion direction.

When the permanent magnet blank F configured as shown in FIG. 17 (similarly in FIGS. 18 and 19) is magnetized and used as a permanent magnet, it can be used such that one side thereof is a side having a high intrinsic coercive force and such that the other side is a side having a high residual magnetic flux density,

The working-effect similar to that in Embodiment 1 is obtained from the permanent magnet blank F (two-element

composite compact 61) produced as described above.

[0057]

Next, FIGS. 18 and 19 showing an example are explained in which the process for combining and integrating the high iHc compact element A and the high Br compact element B is different from the process for forming the composite compact E shown in FIGS. 17(a) to 17(c2) in the integrating process.

[Embodiment 5]

[0058]

As sequentially shown in FIGS. 18(a) to 18(d) illustrating the method of producing a permanent magnet blank F, the high iHc compact element A and the high Br compact element B are formed individually, and they are combined and integrated in the width direction (in the Y-direction) in a way similar to that shown in FIG. 17(c) at the time shown in FIG. 18(b2) to form a composite solid element 10. The above-mentioned composite solid element 10 is a composite solid element obtained by combining and integrating a high iHc solid element 7 (the high iHc compact element A) and a high Br solid element 12 (the high Br compact element B).

The composite solid element 10 is pressed using a hot or warm pressing means to form a composite compact E (two-element composite compact 51) shown in FIG. 18(c). Known

means should only be used as the hot or warm pressing means; for example, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

[0059]

Next, the composite compact E shown in FIG. 18(c) is subjected to plastic working to form a permanent magnet blank F shown in FIG. 18(d). As plastic working, the above-mentioned various plastic working should only be used.

The working-effect similar to that in Embodiment 4 is obtained from the permanent magnet blank F (two-element composite compact 61) produced as described above.

[Embodiment 6]

[0060]

As sequentially shown in FIGS. 19(a) to 19(d) illustrating the method of producing a permanent magnet blank F, the high iH_c compact element A and the high Br compact element B are combined and integrated at the time shown in FIG. 19(a) to form a composite powder element 9.

The above-mentioned composite powder element 9 is a composite powder element formed by combining and integrating a high iH_c powder element 6 (the high iH_c compact element A) and a high Br powder element 11 (the high Br compact element B) (by filling the two elements into the cavity of a die). The filling means for the

powder elements 6 and 11 should only be used in a way similar to that described referring to FIG. 16.

[0061]

Numeral 10 shown in FIG. 19(b) designates a composite solid element formed by pressing the composite powder element 9 using a cold pressing means; this composite solid element 10 is subjected to plastic working using a hot or warm pressing means according to a concept similar to that described earlier in Embodiment 5 to form a permanent magnet blank F shown in FIG. 19(d).

The working-effect similar to that in Embodiment 4 is obtained from the permanent magnet blank F (two-element composite compact 61) produced as described above.

[0062]

Next, examples shown in FIGS. 20, 21 and 22, different in shape from the composite compact E and the permanent magnet blank F shown in FIG. 13, will be described.

In FIG. 20, a method of producing a plate-shaped permanent magnet blank F from a cylinder-shaped composite compact E is provided. In FIG. 21, a method of producing a permanent magnet blank F having an arc-shaped cross section from a composite compact E having a rectangular cross section is provided. In FIG. 22, a method of producing a permanent magnet blank F having a semicylindrical cross section shown in FIG. 22(b) from a composite compact E

having an oval cross section shown in FIG. 22(a) is provided. Furthermore, a method of producing a permanent magnet blank F having a crescent cross section shown in FIG. 22(c) from a composite compact E having an oval cross section shown in FIG. 22(a).

[Embodiment 7]

[0063]

The external dimensions (the diameter D and the length L) of the cylinder-shaped composite compact E shown in FIG. 20(a) should only be set in a way similar to that for the above-mentioned high-density element 4a referring to the above-mentioned FIG. 9.

Furthermore, the respective external dimensions of the high iHc compact element A and the high Br compact element B should only be dimensions such that a composite compact E having the predetermined external dimensions is formed when the two elements are combined and integrated. For example, the dimensions should only be dimensions such that the high iHc compact element A and the high Br compact element B are divided into two equal parts at the alignment face 57.

Next, the external dimensions (the thickness T1, the width W1 and the length L1) of the plate-shaped permanent magnet blank F shown in FIG. 20(b) should only be set in a way similar to that for the above-mentioned permanent magnet blank 60a referring to the above-mentioned FIG. 9.

Known plastic working should only be used as plastic working for forming the composite compact E into the permanent magnet blank F; for example, the forming should only be done by carrying out extrusion in a way similar to that described earlier referring to FIGS. 9 and 10.

[Embodiment 8]

[0064]

Next, the external dimensions (the thickness (the X-direction) T, the width (Y-direction) W and the length (in the Z-direction) L) of the composite compact E shown in FIG. 21(a) should only be set in a way similar to that for the above-mentioned high-density element 4b referring to the above-mentioned FIG. 11. The respective external dimensions of the high iHc compact element A and the high Br compact element B should only be dimensions such that a composite compact E having the predetermined external dimensions is formed when the two elements are combined and integrated. For example, the dimensions should only be dimensions such that the high iHc compact element A and the high Br compact element B are divided into two equal parts at the alignment face 57.

Next, the external dimensions (the thickness (in the X-direction) T1, the arc length (in the Y-direction) W1 on the outer circumferential side, an arc length (in the Y-direction) W2 on the inner circumferential side and a

length (in the Z-direction) L_1) of the permanent magnet blank F having an arc-shaped cross section shown in FIG.

21(b) should only be set in a way similar to that for the above-mentioned permanent magnet blank 60b referring to the above-mentioned FIG. 11.

Known plastic working should only be used as plastic working for forming the composite compact E into the permanent magnet blank F (see FIG. 21(b)); for example, the forming should only be done by carrying out extrusion in a way similar to that described earlier referring to FIG. 11.

[Embodiment 9]

[0065]

Next, the external dimensions (the minor axis diameter D_1 , the major axis diameter D_2 and the length (in the Z-direction) L) of the composite compact E shown in FIG.

22(a) should only be set in a way similar to that for the above-mentioned high-density element 4c referring to FIG.

12. The respective external dimensions of the high iH_c compact element A and the high B_r compact element B for forming the composite compact E shown in FIG. 22(a) should only be dimensions such that a composite compact E having the predetermined external dimensions is formed when the two elements are combined and integrated. For example, the dimensions should only be dimensions such that the high iH_c compact element A and the high B_r compact element B are

divided into two equal parts at the alignment face 57.

The external dimensions (the maximum thickness (in the X-direction) T1, the arc length (in the Y-direction) W1 on the arc side, the width (in the Y-direction) W2 on the straight side and the length (in the Z-direction) L1) of a permanent magnet blank F having a semicylindrical cross section shown in FIG. 22(c) should only be set in a way similar to that for the above-mentioned permanent magnet blank 60c referring to the above-mentioned FIG. 12.

The external dimensions (the maximum thickness (in the X-direction) T1, the arc length (in the Y-direction) W1 on the outer circumferential side, the arc length (in the Y-direction) W2 on the inner circumferential side and the length (in the Z-direction) L1) of the permanent magnet blank F having a crescent cross section shown in FIG. 22(c) should only be set in a way similar to that for the above-mentioned permanent magnet blank 60c referring to the above-mentioned FIG. 12.

Known plastic working should only be used as plastic working for forming the composite compact E into the permanent magnet blank F (see FIGS. 22(b) or FIG. 22(c)); for example, the forming should only be done by carrying out extrusion in a way similar to that described earlier referring to FIG. 11.

[Embodiment 10]

[0066]

Next, when the composite compact E shown in FIG. 13 is configured, the mixture ratios of the magnetic powder Ma and the magnetic powder Mb being used for the high iHc compact element A and the mixture ratios of the magnetic powder Mb and the magnetic powder Ma being used for the high Br compact element B should only be determined by relatively increasing/decreasing the mixture ratios depending on requests with respect to usage (for example, requests with respect to irreversible demagnetization, large/small size and cost). This means that, for example, the mixture ratio of the magnetic powder Ma and the magnetic powder Mb in each of Tables 7, 9, 11, 13, 15 and 17 should only be determined such that the ratio is adjusted so as to conform to the permanent magnet to be requested.

Next, an example in which the ratio is increased or decreased relatively will be described. In this example, when a higher intrinsic coercive force is requested for the high Br compact element B of a permanent magnet formed by magnetizing the permanent magnet blank F shown in FIG. 13(d), a method of producing a permanent magnet blank F capable of meeting the request is provided. The above-mentioned requested intrinsic coercive force is assumed to be an intrinsic coercive force under the conditions shown

in FIG. 34 described later for example, that is, under the conditions in which the intrinsic coercive force is 1.85 MA/m at a distance t of 0 in the thickness direction of the permanent magnet and 1.22 MA/m at a distance t of T_1 , and changes linearly in the distance t between 0 and T_1 . As an example of the magnetic powder Mb being used for the high iH_c compact element A and the high B_r compact element B according to this embodiment, for example, the mixture ratios and thickness ratios shown in Table 7 should only be used. Although two kinds of powders are mixed and used for the second layer, one kind of magnetic powder having a property of $iH_c = 1.53$ MA/m may also be prepared and used directly as a matter of course. The composition of the components at this time is a value obtained by adding all the components of the magnetic powder used in Experiment 2 and the magnetic powder used in Experiment 1 and then by dividing the sum by two.

[0067]

[Table 7]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A (1st layer)	100	0	50
High Br compact element B (2nd layer)	50	50	50

[0068]

The permanent magnet blank F (two-element permanent magnet blank 61) is produced as sequentially shown in FIGS. 13(a) to 13(d) using the high iHc compact element A and the high Br compact element B formed of the materials shown in FIG. 17. The process shown in FIGS. 13(a) to 13(d) should only be carried out in a way similar to that described earlier referring to FIG. 13.

[0069]

Table 8 shows the residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of a permanent magnet obtained by magnetizing the two-layer permanent magnet blank F produced as described above.

Furthermore, the graph of FIG. 23 shows the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of this permanent magnet.

[0070]

[Table 8]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.36	1.85	3.6
High Br compact element B side(2nd layer)	1.415	1.535	1.8
Permanent magnet	1.3875	—	2.7

[0071]

As shown in the above-mentioned Table 8 and FIG. 23, the intrinsic coercive force on the high iHc compact element A side of the permanent magnet is very high (1.85 MA/m) since the Dy content rate is 3.6 mass%. Furthermore, Br is 1.415 T on the high Br compact element B side of the permanent magnet, and Br in the whole permanent magnet is 1.3875 T on the average in the high iHc compact element A and the high Br compact element B, thereby having a high residual magnetic flux density. Hence, in a way similar to that described earlier referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

Moreover, as shown in Table 8, the amount of use of Dy in the whole permanent magnet is 2.7 mass% on the average in the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high

intrinsic coercive force can be obtained using a scarce amount of expensive Dy.

[Embodiment 11]

[0072]

Next, an example is described referring to FIG. 24, in which an intermediate compact element C is disposed between the high iHc compact element A and the high Br compact element B and the elements are combined and integrated to form a composite compact E, the composite compact E being different from the composite compact E shown in FIG. 13(c2) in the configuration described above. As sequentially shown in FIGS. 24(a) to 24(d), FIG. 24 shows an example in which the high iHc compact element A, the high Br compact element B and the intermediate compact element C are formed individually, they are combined and integrated to form a composite compact E (three-element (multiple-element) composite compact 52), and the composite compact E is subjected to plastic working to form a permanent magnet blank F (three-element permanent magnet blank 63).

As shown in FIG. 24, in the method of producing the permanent magnet blank F, the high iHc compact element A, the high Br compact element B and the intermediate compact element C formed of a magnetic powder Mc for the intermediate element, the above-mentioned intermediate compact element C being disposed between the high iHc

compact element A and the high Br compact element B, are combined and integrated to form a composite compact E; the material properties of the magnetic powder Mc for the above-mentioned intermediate compact element C are set to properties such that the intrinsic coercive force becomes lower sequentially in the direction from the above-mentioned high iHc compact element A to the above-mentioned high Br compact element B and such that the residual magnetic flux density becomes lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iHc compact element A in the above-mentioned combined and integrated state of the composite compact E (the magnetic powder having these material properties is also referred to as the "magnetic powder Mc" or the "magnetic powder Mc for the intermediate element" in the present invention); furthermore, the above-mentioned composite compact E is subjected to plastic working so as to be provided with magnetic anisotropy.

[0073]

This matter will be described in more detail referring to FIG. 24.

The high iHc high-density element 8 in the high iHc compact element A serving as the first layer and the high Br high-density element 13 in the high Br compact element B serving as the third layer in FIG. 24 should be formed

according to a concept similar to that described referring to FIG. 13.

Next, as examples of the magnetic powders Ma and Mb being used for the above-mentioned high iHc compact element A and high Br compact element B, those having the mixture ratios and thickness ratios shown in Table 9, for example, should only be used.

[0074]

[Table 9]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A (1st layer)	100	0	33.34
Intermediate compact element C (2nd layer)	66.67	33.33	33.33
High Br compact element B (3rd layer)	33.33	66.67	33.33

[0075]

In the intermediate compact element C serving as the second layer shown in each of FIGS. 24(a), 24(b) and 24(c), numeral 16 designates an intermediate powder element formed by filling the magnetic powder Mc into the cavity (not shown) of the die of a cold press. The magnetic powder Mc should only be produced using a known method in a way similar to that for the above-mentioned magnetic powder M described earlier referring to FIG. 1. The material

properties of the magnetic powder Mc are set to properties having conditions such that the intrinsic coercive force becomes lower sequentially in the direction from the high iHc compact element A to the high Br compact element B and such that the residual magnetic flux density becomes lower sequentially in the direction from the high Br compact element B to the high iHc compact element A in the state of the composite compact E shown in FIG. 24(c2). Furthermore, the magnetic powder Mc may be formed by mixing the magnetic powder Ma and magnetic powder Mb in appropriate ratios (by mixing the amounts that can be easily assumed according to Tables 9, 11, 13, 15 and 17), or the composition of the magnetic alloy may be increased or decreased for each of the magnetic powder Ma and magnetic powder Mb. In that case, the magnetic powder Mc should only satisfy the conditions such that the intrinsic coercive force becomes lower sequentially in the direction from the high iHc compact element A to the high Br compact element B and such that the residual magnetic flux density becomes lower sequentially in the direction from the high Br compact element B to the high iHc compact element A in the state of the composite compact E. For example, the magnetic powder Mc shown in above-mentioned Table 9 may also be used. Numeral 17 in FIG. 24(b) designates an intermediate solid element formed by pressing the intermediate powder element

16 using a cold pressing means, and numeral 18 in FIG.

24(c) designates a high Br high-density element produced by pressing the intermediate solid element 17 using a hot or warm pressing means. As the cold, hot or warm pressing means, known means should only be used; for example, cold, hot or warm pressing means should only be used in a way similar to that described earlier referring to FIG. 1.

In the above-mentioned description, the term "compact element" is a general term referring to a powder element, solid element or high-density element obtained in the process of forming a composite compact from a magnetic powder. Furthermore, the words, such as high iHc, high Br and intermediate, in the compact element are words used to distinguish the material properties from those of others.

[0076]

The external dimensions of the high iHc high-density element 8, the high Br high-density element 13 and the intermediate high-density element 18 should only be dimensions such that a composite compact E having the predetermined external dimensions is formed when all the elements are combined and integrated. For example, the high iHc high-density element 8, the Br high-density element 13 and the intermediate high-density element 18 should only have a thickness T2 of 12 mm, a width W2 of 19 mm and a length L2 of 25 mm. Hence, the composite compact

E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm.

[0077]

Next, the high iHc high-density element 8 (the high iHc compact element A), the high Br high-density element 13 (the high Br compact element B) and the intermediate high-density element 18 (the intermediate compact element C), produced individually, are combined and integrated as shown in FIG. 24(c2) to produce the composite compact E (three-element composite compact 52). This combination should only be done according to a concept similar to that described referring to FIG. 13.

In the present invention, such a product obtained by combining and integrating the multiple compact elements (the compact elements to which letters A and B or letters A, B and C are assigned) as described above is referred to as a composite compact E.

[0078]

Next, the composite compact E shown in FIG. 24(c2) is subjected to plastic working to form a permanent magnet blank F (three-element permanent magnet blank 62) shown in FIG. 24(d). The above-mentioned various plastic working processes should only be used as plastic working processes.

Although the external dimensions of the permanent magnet blank F are different depending on the plastic

working carried out for the composite compact E, when extrusion similar to that for Comparative Example 1 in the above-mentioned Experiment 1 is carried out for example, and when the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm, the permanent magnet blank F has a thickness T1 of 8 mm, a width W1 of 40 mm and a length L1 of 53.4 mm.

[0079]

Table 10 shows the residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet obtained by magnetizing the three-layer permanent magnet blank F produced as described above.

Furthermore, the graph of FIG. 25 shows the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of the permanent magnet.

[0080]

[Table 10]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.36	1.85	3.6
Intermediate compact element C (2nd layer)	1.397	1.64	2.4
High Br compact element B side(3rd layer)	1.433	1.43	1.2
Permanent magnet	1.397	---	2.4

[0081]

As shown in the above-mentioned Table 10 and FIG. 25,

the intrinsic coercive force on the high iHc compact element A side of the permanent magnet is very high (1.85 MA/m) since the Dy content rate is 3.6 mass%. Furthermore, Br is 1.433 T on the high Br compact element B side of the permanent magnet, and Br in the whole permanent magnet is 1.397 T on the average in all the layers, thereby having a high residual magnetic flux density. Hence, in a way similar to that described earlier referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

Moreover, as shown in Table 10, the amount of use of Dy in the whole permanent magnet is 2.4 mass% on the average in the three elements by disposing the intermediate compact element C between the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high intrinsic coercive force can be obtained using a scarce amount of expensive Dy.

[0082]

Next, an example is described referring to FIGS. 26 to 32, in which multiple intermediate compact elements C are disposed between the high iHc compact element A and the high Br compact element B and the elements are combined and

integrated to form a composite compact E, the composite compact E being different from the composite compact E shown in FIG. 13(c2) in the configuration described above.

FIG. 26 shows an example in which the high iHc compact element A, the high Br compact element B and multiple (two-element) intermediate compact elements C are formed individually, they are combined and integrated to form a composite compact E (four-element (multiple-element) composite compact 53), and the composite compact E is subjected to the above-mentioned plastic working to form a permanent magnet blank F.

FIG. 28 shows an example in which the high iHc compact element A, the high Br compact element B and multiple (three-element) intermediate compact elements C are formed individually, they are combined and integrated to form a composite compact E (five-element (multiple-element) composite compact 54), and the composite compact E is subjected to the above-mentioned plastic working to form a permanent magnet blank F (five-element permanent magnet blank 64).

FIG. 30 shows an example in which the high iHc compact element A, the high Br compact element B and multiple (eight-element) intermediate compact elements C are formed individually, they are combined and integrated to form a composite compact E (ten-element (multiple-element)

composite compact 55), and the composite compact E is subjected to the above-mentioned plastic working to form a permanent magnet blank F (ten-element permanent magnet blank 65).

Furthermore, FIG. 32 is a figure illustrating that the Dy content rate decreases and the Br of the whole permanent magnet increases when the number of the intermediate compact elements C is increased to 18 in the above-mentioned FIG. 30.

[Embodiment 12]

[0083]

As shown in FIG. 26, in the method of producing a permanent magnet blank F, the high iHc compact element A, the high Br compact element B and the multiple intermediate compact elements formed of multiple magnetic powders Mc having material properties different from one another and being used for the intermediate elements, the above-mentioned multiple intermediate compact elements C being disposed between the above-mentioned high iHc compact element A and the above-mentioned high Br compact element B, are combined and integrated to form a composite compact E; the material properties of the respective magnetic powders Mc for the above-mentioned multiple intermediate compact elements C are set to properties such that the respective intrinsic coercive forces become lower sequentially in the

direction from the above-mentioned high iHc compact element A to the above-mentioned high Br compact element B and such that the respective residual magnetic flux densities become lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iHc compact element A in the above-mentioned combined and integrated state of the composite compact E (the magnetic powders having these material properties are also referred to as the "magnetic powders Mc" or the "magnetic powders Mc for the intermediate elements"). Furthermore, the above-mentioned composite compact E is subjected to plastic working so as to be provided with magnetic anisotropy.

[0084]

This matter will be described in more detail referring to FIG. 26.

The high iHc high-density element 8 in the high iHc compact element A serving as the first layer and the high Br high-density element 13 in the high Br compact element B serving as the fourth layer in FIG. 26 should be formed according to a concept similar to that described referring to FIG. 13.

Next, as examples of the magnetic powders M being used for the above-mentioned high iHc compact element A and high Br compact element B, those having the mixture ratios and

thickness ratios shown in Table 11, for example, should only be used.

[0085]

[Table 11]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A (1st layer)	100	0	25
Intermediate compact element C (2nd layer)	75	25	25
Intermediate compact element C (3rd layer)	50	50	25
High Br compact element B (4th layer)	25	75	25

[0086]

Next, the intermediate high-density elements 23a and 23b of the multiple intermediate compact elements C (the intermediate compact element 20a and the intermediate compact element 20b) in the second and third layers shown in FIG. 26(c) should only be formed according to a concept similar to that for the intermediate high-density element 18 described referring to FIG. 24. The material properties of the respective multiple magnetic powders Mc for the intermediate elements, having material properties different from one another and being used for the above-mentioned multiple intermediate compact elements C, should only be

set to properties such that the intrinsic coercive forces become lower sequentially in the direction from the above-mentioned high iHc compact element A to the above-mentioned high Br compact element B and such that the residual magnetic flux densities become lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iHc compact element A in the above-mentioned combined and integrated state of the composite compact E. Furthermore, the above-mentioned multiple magnetic powders Mc may be formed by mixing the magnetic powder Ma and the magnetic powder Mb in appropriate ratios (by mixing the amounts that can be easily assumed according to Tables 11, 13, 15 and 17), or the composition of the magnetic alloy may be increased or decreased for each of the magnetic powder Ma and magnetic powder Mb. In that case, the magnetic powders Mc should only satisfy the conditions such that the respective intrinsic coercive forces become lower sequentially in the direction from the above-mentioned high iHc compact element A to the above-mentioned high Br compact element B and such that the respective residual magnetic flux densities become lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iHc compact element A in the state of the composite compact E. For example, as examples of the respective

material properties of the above-mentioned multiple magnetic powders Mc, those having the mixture ratios and thickness ratios shown in Table 11, for example, should only be used for the layers including the first to fourth layers.

[0087]

The respective external dimensions of the high iHc high-density element 8, the high Br high-density element 13 and the intermediate high-density elements 23a and 23b serving as the second and third layers shown in FIG. 26(c) should only be dimensions such that a composite compact E having the predetermined external dimensions is formed when these are combined and integrated. For example, the high iHc high-density element 8, the high-density element 13 and the intermediate high-density elements 23a and 23b serving as the second and third layers should only have a thickness T2 of 9 mm, a width W2 of 19 mm and a length L2 of 25 mm. Hence, the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm.

[0088]

Next, the high iHc high-density element 8 (the high iHc compact element A), the high Br high-density element 13 (the high Br compact element B) and the intermediate high-density elements 23a and 23b serving as the second and third layers (the multiple intermediate compact elements C),

respectively produced individually, are combined and integrated as shown in FIG. 24(c2) to produce the composite compact E (four-element composite compact 53). This combination should only be done according to a concept similar to that described referring to FIG. 13.

[0089]

Next, the composite compact E shown in FIG. 26(c2) is subjected to plastic working to form a permanent magnet blank F (four-element permanent magnet blank 63) shown in FIG. 26(d). The above-mentioned various plastic working processes should only be used as plastic working processes.

Although the external dimensions of the permanent magnet blank F are different depending on the plastic working carried out for the composite compact E, when extrusion similar to that for Comparative Example 1 in the above-mentioned Experiment 1 is carried out for example, and when the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm, the permanent magnet blank F has a thickness T1 of 8 mm, a width W1 of 40 mm and a length L1 of 53.4 mm.

[0090]

Table 12 shows the residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet obtained by magnetizing the four-layer permanent magnet blank F produced as described above.

Furthermore, the graph of FIG. 27 shows the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of the permanent magnet.

[0091]

[Table 12]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.36	1.85	3.6
Intermediate compact element C (2nd layer)	1.3875	1.6925	2.7
Intermediate compact element C(3rd layer)	1.415	1.535	1.8
High Br compact element B side(4th layer)	1.4425	1.3775	0.9
Permanent magnet	1.40125	—	2.25

[0092]

As shown in the above-mentioned Table 12 and FIG. 27, the intrinsic coercive force on the high iHc compact element A side of the permanent magnet is very high (1.85 MA/m) since the Dy content rate is 3.6 mass%. Furthermore, Br is 1.4425 T on the high Br compact element B side of the permanent magnet, and Br in the whole permanent magnet is 1.40125 T on the average in all the layers, thereby having a high residual magnetic flux density. Hence, in a way similar to that described earlier referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in

magnetic properties.

Moreover, as shown in Table 12, the amount of use of Dy in the whole permanent magnet is 2.25 mass% on the average in the four elements by disposing the multiple (two-layer) intermediate compact elements C between the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high intrinsic coercive force can be obtained using a scarce amount of expensive Dy.

[Embodiment 13]

[0093]

Next, FIG. 28 will be described.

The high iHc high-density element 8 in the high iHc compact element A serving as the first layer and the high Br high-density element 13 in the high Br compact element B serving as the fifth layer shown in FIG. 28 should be formed according to a concept similar to that described referring to FIG. 13. Furthermore, the respective multiple intermediate high-density elements 33a to 33c in the intermediate compact elements C (intermediate compact elements 30a to 30c) serving as the second to fourth layers should be formed according to a concept similar to that described referring to FIG. 26. For example, as examples of the magnetic powders M being used for the above-

mentioned high iHc compact element A, high Br compact element B and multiple intermediate compact elements C, those having the mixture ratios shown in Table 13 may be used. The thickness ratios of the high iHc compact element A, the high Br compact element B and the multiple intermediate compact elements C in the composite compact E should only be those shown in Table 13, for example.

[0094]

[Table 13]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A (1st layer)	100	0	20
Intermediate compact element C (2nd layer)	80	20	20
Intermediate compact element C (3rd layer)	60	40	20
Intermediate compact element C (4th layer)	40	60	20
High Br compact element B (5th layer)	20	80	20

[0095]

The external dimensions of the high iHc high-density element 8, the high Br high-density element 13 and the intermediate high-density elements 33a to 33c serving as the second to fourth layers shown in FIG. 26(c) should only be dimensions such that a composite compact E (five-element

(multiple-element) composite compact 54) having the predetermined external dimensions is formed when these are combined and integrated; for example, the high iHc high-density element 8, the Br high-density element 13 and the intermediate high-density elements 33a and 33b should only have a thickness T2 of 7.2 mm, a width W2 of 19 mm and a length L2 of 25 mm. Hence, the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm.

[0096]

Next, the high iHc high-density element 8 (the high iHc compact element A), the high Br high-density element 13 (the high Br compact element B) and the intermediate high-density elements 33a to 33c serving as the second to fourth layers (the multiple intermediate compact elements C), respectively produced individually, are combined and integrated as shown in FIG. 28(c2) to produce the composite compact E (five-element composite compact 54). This combination should only be done according to a concept similar to that described referring to FIG. 13.

[0097]

Next, the composite compact E is subjected to plastic working to form a permanent magnet blank F (five-element permanent magnet blank 64) shown in FIG. 28(d). The above-mentioned various plastic working processes should only be

used as plastic working processes.

Although the external dimensions of the permanent magnet blank F are different depending on the plastic working carried out for the composite compact E, when extrusion similar to that for Comparative Example 1 in the above-mentioned Experiment 1 is carried out for example, and when the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm, the permanent magnet blank F has a thickness T1 of 8 mm, a width W1 of 40 mm and a length L1 of 53.4 mm.

[0098]

Table 14 shows the residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet obtained by magnetizing the five-layer permanent magnet blank F produced as described above.

Furthermore, the graph of FIG. 29 shows the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of the permanent magnet.

[0099]

[Table 14]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.36	1.85	3.6
Intermediate compact element C (2nd layer)	1.382	1.724	2.88
Intermediate compact element C(3rd layer)	1.404	1.598	2.16
Intermediate compact element C (4th layer)	1.426	1.472	1.44
High Br compact element B side(5th layer)	1.448	1.346	0.72
Permanent magnet	1.404	---	2.16

[0100]

As shown in the above-mentioned Table 14 and FIG. 29, the intrinsic coercive force on the high iHc compact element A side of the permanent magnet is very high (1.85 MA/m) since the Dy content rate is 3.6 mass%. Furthermore, Br is 1.448 T on the high Br compact element B side of the permanent magnet, and Br in the whole permanent magnet is 1.404 T on the average in all the layers, thereby having a high residual magnetic flux density. Hence, in a way similar to that described referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

Moreover, as shown in Table 14, the amount of use of Dy in the whole permanent magnet is 2.16 mass% on the average in the five elements by disposing the multiple

(three-layer) intermediate compact elements C between the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high intrinsic coercive force can be obtained using a scarce amount of expensive Dy.

[Embodiment 14]

[0101]

Next, FIG. 30 will be described. In the description referring to FIG. 30, the respective external views of the high iHc compact element A, the high Br compact element B and the intermediate compact elements C, serving as the first to tenth layers, should be described properly; however, the views of the third to eighth layers are omitted since they are similar to the external view of the second layer.

The high iHc high-density element 8 in the high iHc compact element A serving as the first layer and the high Br high-density element 13 in the high Br compact element B serving as the tenth layer shown in FIG. 30 should be formed according to a concept similar to that described referring to FIG. 13. Furthermore, the respective multiple intermediate high-density elements in the intermediate compact elements C serving as the second to ninth layers shown in FIG. 30(c) should be formed according to a concept

similar to that described referring to FIG. 26. For example, as examples of the magnetic powders M being used for the above-mentioned high iHc compact element A, multiple intermediate compact elements C and high Br compact element B, such elements should be used referring to the mixture ratios shown in Table 15, whereby the permanent magnet blank F equipped with the multiple intermediate compact elements C according to the present invention can be attained. The ratios of the high iHc compact element A, the multiple intermediate compact elements C and the high Br compact element B in the composite compact E should only be those shown in Table 15.

[0102]

[Table 15]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A (1st layer)	100	0	10
Intermediate compact element C (2nd layer)	90	10	10
Intermediate compact element C (3rd layer)	80	20	10
Intermediate compact element C (4th layer)	70	30	10
Intermediate compact element C (5th layer)	60	40	10
Intermediate compact element C (6th layer)	50	50	10
Intermediate compact element C (7th layer)	40	60	10
Intermediate compact element C (8th layer)	30	70	10
Intermediate compact element C (9th layer)	20	80	10
High Br compact element B (10th layer)	10	90	10

[0103]

The external dimensions of the high iHc high-density element 8 (the first layer), the high Br high-density element 13 (the tenth layer) and the intermediate high-density elements (the second to ninth layers) shown in FIG. 30(c) should only be dimensions such that a composite compact E (ten-element (multiple-element) composite compact 55) having the predetermined external dimensions is formed when these are combined and integrated; for example, the

high iHc high-density element 8, the high-density element 13 and the multiple intermediate high-density elements (the second to ninth layers) should only have a thickness T2 of 3.6 mm, a width W2 of 19 mm and a length L2 of 25 mm.

Hence, the composite compact E has a thickness T of 36 mm, a width W of 19 mm and a length L of 25 mm.

[0104]

Next, the high iHc high-density element 8 (the high iHc compact element A), the high Br high-density element 13 (the high Br compact element B) and the multiple intermediate high-density elements (the multiple intermediate compact elements C) serving as the second to ninth layers, respectively produced individually, are combined and integrated as shown in FIG. 30(c2) to produce the composite compact E (ten-element composite compact 55).

The above-mentioned combination arrangement sequence should be in the order of the first to tenth layers.

[0105]

Next, the composite compact E shown in FIG. 30(c2) is subjected to plastic working to form a permanent magnet blank F (ten-element permanent magnet blank 65) shown in FIG. 30(d). The above-mentioned various plastic working processes should only be used as plastic working processes.

[0106]

Table 16 shows the residual magnetic flux density (Br),

the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet obtained by magnetizing the ten-layer permanent magnet blank F produced as described above.

Furthermore, the graph of FIG. 31 shows the relationship between the residual magnetic flux density (Br) and the intrinsic coercive force (iHc) of the permanent magnet.

[0107]

[Table 16]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.360	1.850	3.60
Intermediate compact element C (2nd layer)	1.371	1.787	3.24
Intermediate compact element C(3rd layer)	1.382	1.724	2.88
Intermediate compact element C (4th layer)	1.393	1.661	2.52
Intermediate compact element C(5th layer)	1.404	1.598	2.16
Intermediate compact element C(6th layer)	1.415	1.535	1.80
Intermediate compact element C(7th layer)	1.426	1.472	1.44
Intermediate compact element C(8th layer)	1.437	1.409	1.08
Intermediate compact element C(9th layer)	1.448	1.346	0.72
High Br compact element B side(10th layer)	1.459	1.283	0.36
Permanent magnet	1.4095	—	1.98

[0108]

As shown in the above-mentioned Table 16 and FIG. 31, the intrinsic coercive force on the high iHc compact element A side of the permanent magnet is very high (1.85 MA/m) since the Dy content rate is 3.6 mass%. Furthermore, Br is 1.459 T on the high Br compact element B side of the

permanent magnet, and Br in the whole permanent magnet is 1.4095 T on the average in all the layers, thereby having a high residual magnetic flux density. Hence, in a way similar to that described referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

Moreover, as shown in Table 16, the amount of use of Dy in the whole permanent magnet is 1.98 mass% on the average in the ten elements by disposing the multiple intermediate compact elements C between the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high intrinsic coercive force can be obtained using a scarce amount of expensive Dy.

[0109]

Next, FIG. 33 will be described. In the above-mentioned FIGS. 13 and 16, an example is described in which when the two-element composite compact E is formed, the high iHc powder element 6 and the high Br powder element 11 being mutually in an individual state as shown in FIG. 13(a) or the high iHc powder element 6 and the high Br powder element 11 being accommodated in parallel inside a cavity as shown in FIG. 16(a) are used selectively.

FIG. 33 illustrates an example in which powder elements are selectively used after the examples of FIGS. 13 and 16 when a multiple-element composite compact E is formed. More specifically, a high iH_c powder element 6 that is formed of the magnetic powder Ma being high in intrinsic coercive force in comparison with a high Br powder element 11 and being low in residual magnetic flux density in comparison with the high Br powder element 11, the high Br powder element 11 that is formed of the magnetic powder Mb being high in residual magnetic flux density in comparison with the high iH_c powder element 6 and being low in intrinsic coercive force in comparison with the high iH_c powder element 6, and multiple intermediate powder elements 41 that are formed of the multiple magnetic powders Mc being used for the intermediate elements and mutually different in material properties are combined in a state in which the powder elements are mutually arranged in parallel inside a cavity 5 and in a state in which the above-mentioned multiple intermediate powder elements are disposed between the above-mentioned high iH_c powder element 6 and the above-mentioned high Br powder element 11, and they are integrated using a pressing means to form a composite compact E, whereby the composite compact E for a permanent magnet is produced in which the material properties of the

respective magnetic powders Mc for the above-mentioned multiple intermediate powder elements 41 are set to properties such that the respective intrinsic coercive forces become lower sequentially in the direction from the above-mentioned high iHc compact element A to the above-mentioned high Br compact element B and such that the respective residual magnetic flux densities become lower sequentially in the direction from the above-mentioned high Br compact element B to the above-mentioned high iHc compact element A in the above-mentioned combined and integrated state of the composite compact E.

[0110]

This matter will be described further; it has been described earlier in FIG. 30(c2) that the ten-element composite compact E exemplified as a multiple-element composite compact for a permanent magnet should only be formed using the powder elements shown in the column (a) of FIG. 30. However, as obvious from the description referring to FIGS. 13 and 16, when the composite compact E is formed, a composite powder element 9 that is formed by filling the magnetic powders Mc having different properties and being used for the second to ninth layers into a cavity in parallel between the magnetic powder Ma and the magnetic powder Mb should only be selectively used as shown in FIG. 33(a) according to the concept described referring to FIG.

16. In the figure, numeral 9 designates a composite powder element formed by combining the high iHc powder element 6, the high Br powder element 11 and the multiple intermediate powder elements 41 that are formed of the multiple magnetic powders Mc being used for the intermediate elements and mutually different in material properties while the above-mentioned multiple intermediate powder elements are disposed between the above-mentioned high iHc powder element 6 and the above-mentioned high Br powder element 11 mutually in parallel inside the cavity 5. This composite powder element 9 is pressed using a known pressing means, thereby integrated to form a composite compact E. Numeral 10 designates a composite solid element formed by combining and integrating the high iHc compact element A, the high Br compact element B and the multiple intermediate compact elements C in a state in which the above-mentioned multiple intermediate compact elements C are disposed between the above-mentioned high iHc compact element A and the above-mentioned high Br compact element B.

[0111]

According to the production method of combining and integrating the powder elements shown in the column (a) of the above-mentioned FIG. 30, the permanent magnet blank F can be provided at low cost in comparison with the method shown in FIG. 30. More specifically, in an example in

which the respective powder elements are formed individually as in the case of FIG. 30, multiple (for example, 21) pressing operations are required; in contrast, in an example in which multiple powder elements are arranged inside a cavity as shown in FIG. 33, only a few (for example, three) pressing operations are required. The magnetic properties of the permanent magnets obtained by magnetizing the permanent magnet blanks F shown in FIGS. 33 and 30 were the same.

Furthermore, even when other multiple composite compacts E are formed using the intermediate powder elements 16, 21 and 31 shown in the above-mentioned FIGS. 24 to 28, the composite compacts E having the corresponding number of layers should only be formed according to a concept similar to that described above by reducing the numbers of the intermediate powder elements 41, intermediate solid elements 42, etc. in FIGS. 33(a), 33(b) and 33(c) so as to respond to requests.

In the examples shown in the above-mentioned FIGS. 13 to 33, the high iHc compact element A, the high Br compact element B and the intermediate compact elements C constituting the composite compact E are described so as to have the same dimensions. However, the size in each alignment direction (the size in the thickness direction or the width direction) should only be increased or decreased

appropriately depending on the request for irreversible demagnetization, requests with respect to size and cost, etc.

[Embodiment 15]

[0112]

Next, FIG. 32 will be described. As described earlier, FIG. 32 is used to illustrate the relationship between the intrinsic coercive force (iH_c) and the residual magnetic flux density (B_r) when the number of the layers of the intermediate compact elements C shown in FIG. 30 is increased by 10 layers to 18 layers. The figure for Embodiment 15, that is, the figure corresponding to FIG. 30 for Embodiment 14, is a figure in which the number of the layers of the intermediate compact elements C is increased by 10 from the number of the layers in FIG. 30. Hence, figure representation is omitted as self-evident.

[0113]

The high iH_c high-density element in the high iH_c compact element A serving as the first layer and the high B_r high-density element in the high B_r compact element B serving as the 20th layer should be formed according to a concept similar to that described referring to FIG. 13. Furthermore, the multiple intermediate high-density elements of the intermediate compact elements C serving as the second to 19th layers should be formed according to a

concept similar to that described referring to FIG. 26.

For example, as examples of the respective magnetic powders M being used for the high iHc compact element A, the 18-layer intermediate compact elements C and the high Br compact element B according to Embodiment 15, those having the mixture ratios shown in Table 17 for example may also be used. Moreover, the ratios of the high iHc compact element A, the multiple intermediate compact elements C and the high Br compact element B in the composite compact E should only be those shown in Table 17.

[0114]

[Table 17]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A side (1st layer)	100	0	5
Intermediate compact element C (2nd layer)	95	5	5
Intermediate compact element C (3rd layer)	90	10	5
Intermediate compact element C (4th layer)	85	15	5
Intermediate compact element C (5th layer)	80	20	5
Intermediate compact element C (6th layer)	75	25	5
Intermediate compact element C (7th layer)	70	30	5
Intermediate compact element C (8th layer)	65	35	5
Intermediate compact element C (9th layer)	60	40	5
Intermediate compact element C (10th layer)	55	45	5
Intermediate compact element C (11th layer)	50	50	5
Intermediate compact element C (12th layer)	45	55	5
Intermediate compact element C (13th layer)	40	60	5
Intermediate compact element C (14th layer)	35	65	5
Intermediate compact element C (15th layer)	30	70	5
Intermediate compact element C (16th layer)	25	75	5
Intermediate compact element C (17th layer)	20	80	5
Intermediate compact element C (18th layer)	15	85	5
Intermediate compact element C (19th layer)	10	90	5
High Br compact element B side (20th layer)	5	95	5

Next, in the method of producing a permanent magnet blank F using the high iHc compact element A, the 18-layer intermediate compact elements C and the high Br compact element B, a 20-layer composite compact E and a permanent magnet blank F are formed from the high iHc compact element

A, the 18-layer intermediate compact elements C and the high Br compact element B formed of the magnetic powders having the material properties shown in Table 17. The processes thereof should only be carried out according to a concept similar to that described referring to FIG. 30.

The residual magnetic flux density (Br), the intrinsic coercive force (iHc) and the Dy content rate of the permanent magnet blank F (the 20-element permanent magnet blank) produced as described above are shown in Table 18.

[0115]

[Table 18]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.3600	1.8500	3.6
Intermediate compact element C (2nd layer)	1.3655	1.8185	3.42
Intermediate compact element C(3rd layer)	1.3710	1.7870	3.24
Intermediate compact element C (4th layer)	1.3765	1.7555	3.06
Intermediate compact element C(5th layer)	1.3820	1.7240	2.88
Intermediate compact element C(6th layer)	1.3875	1.6925	2.70
Intermediate compact element C(7th layer)	1.3930	1.6610	2.52
Intermediate compact element C(8th layer)	1.3985	1.6295	2.34
Intermediate compact element C(9th layer)	1.4040	1.5980	2.16
Intermediate compact element C(10th layer)	1.4095	1.5665	1.98
Intermediate compact element C(11th layer)	1.4150	1.5350	1.80
Intermediate compact element C(12th layer)	1.4205	1.5035	1.62
Intermediate compact element C(13th layer)	1.4260	1.4720	1.44
Intermediate compact element C(14th layer)	1.4315	1.4405	1.26
Intermediate compact element C(15th layer)	1.4370	1.4090	1.08
Intermediate compact element C(16th layer)	1.4425	1.3775	0.90
Intermediate compact element C(17th layer)	1.4480	1.3460	0.72
Intermediate compact element C(18th layer)	1.4535	1.3145	0.54
Intermediate compact element C(19th layer)	1.4590	1.2830	0.36
High Br compact element B side(20th layer)	1.4645	1.2515	0.18
Permanent magnet	1.41225	-	1.89

[0116]

In this embodiment, as understandable from Table 18 and FIG. 32, the one side 67 of the permanent magnet blank F (the high iHc compact element side) is high in intrinsic coercive force (1.85 MA/m). Furthermore, Br is 1.4645 T on the high Br compact element B side of the permanent magnet,

and Br in the whole permanent magnet is 1.41225 T on the average in all the layers, thereby having a high residual magnetic flux density. Hence, similarly as described referring to FIG. 13, the magnetic properties of the whole permanent magnet hardly deteriorate, and the permanent magnet can be used for a long life period as a permanent magnet being excellent in magnetic properties.

Moreover, as shown in Table 18, the amount of use of Dy in the whole permanent magnet is 1.89 mass% on the average in the 20 layers by disposing the multiple intermediate compact elements C between the high iHc compact element A and the high Br compact element B; hence, it is characterized in that a permanent magnet capable of delivering the above-mentioned high intrinsic coercive force can be obtained using a scarce amount of expensive Dy. [0117]

In Embodiments 10 to 15 described above referring to FIGS. 24 to 33, examples are described in which the high iHc compact element A, the intermediate compact elements C and the high Br compact element B are combined and integrated in the X-direction to form the composite compact E. However, when the high iHc compact element A, the intermediate compact elements C and the high Br compact element B are combined and integrated to form the composite compact E, the elements may be combined in the Y-direction

to form the composite compact E according to a concept similar to that described referring to FIG. 17(c).

[0118]

Next, the specific measurements of the magnetic properties of the permanent magnet blanks F shown in the above-mentioned FIGS. 13, 23, 24, 26, 28, 30, 32 and 33 are conducted as described below.

Similarly as described in Experiment 1, segments having a width of 8 mm, a length of 8 mm and a thickness of 8 mm were taken from the central portions in the width and length directions of the permanent magnet blanks F and shaved in the thickness direction until each element portion became a single layer; furthermore, the layers are overlaid multiply so that the thickness became the same thickness (8 mm) as in Experiment 1, and the obtained products were used as magnetic measurement samples for respective elements. Then, the samples magnetized in a magnetic field of 3.2 MA/m were used for measurements, and the residual magnetic flux density and intrinsic coercive force were measured.

Moreover, the specific measurements of the magnetic properties of the permanent magnet blanks F shown in the above-mentioned FIGS. 17 to 19 were conducted as described below. Segments having a width of 8 mm, a length of 8 mm and a thickness of 8 mm were taken from the central

portions in the width and length directions of the respective elements of the permanent magnet blanks F and were used as magnetic measurement samples for respective elements. Then, the samples magnetized in a magnetic field of 3.2 MA/m were used for measurements, and the residual magnetic flux density and intrinsic coercive force were measured.

[0119]

Next, examples in which the material properties of the magnetic powders M being used to form the high iH_c compact element A, the high B_r compact element B and the intermediate compact elements C are selected will be described referring to FIGS. 34 to 41.

When the predetermined intrinsic coercive force shown in FIG. 34 is requested for the permanent magnet blank F, FIGS. 34 to 41 are used to illustrate design examples for selecting the material properties of the magnetic powders M in response to the request so as not to cause irreversible demagnetization. In the case that a permanent magnet obtained by magnetizing the permanent magnet blank F is used, when one face of the permanent magnet is placed in an environment exposed to high heat or the like and when the other face is placed in an environment not exposed to such high heat, the intrinsic coercive force requested for the permanent magnet has distribution inside the permanent

magnet. For example, the distribution of the requested intrinsic coercive force is described in the case of the conditions shown in FIG. 34. More specifically, t denotes the distance in the thickness direction of the permanent magnet, and conditions are assumed in which the intrinsic coercive force is requested to be 1.22 MA/m at $t = T_1$ and to change linearly in the distance t between 0 and T_1 . A known means should only be used as a means of obtaining the intrinsic coercive force requested for the permanent magnet.

In addition, the intrinsic coercive force may be made slightly larger at this time in consideration of a certain degree of safety factor. Irreversible demagnetization does not occur when the intrinsic coercive force in the region (the shaded part) above the inclined line in FIG. 34 is applied to the respective portions in the thickness direction of the permanent magnet.

[0120]

Next, such a two-layer permanent magnet blank F as exemplified in Embodiment 10 will be described referring to FIG. 35. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the two layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first layer has 1.85 MA/m and the second layer has 1.535 MA/m as

shown in FIG. 35.

Hence, for the purpose of attaining the intrinsic coercive forces using the two kinds of the magnetic powders: the magnetic powder M used in Experiment 2 and the magnetic powder M used in Experiment 1, the magnetic powder used in Experiment 2 should be used 100% for the first layer, and the magnetic powder used in Experiment 2 and the magnetic powder used in Experiment 1 should be mixed in the ratio of 50 to 50% for the second layer for example, as shown in the above-mentioned Table 7.

At this time, the magnetic properties of the second layer correspond to the 50:50% position shown in FIG. 23, the ratio being the same as the mixture ratio of the magnetic powder having the magnetic properties and used in Experiment 2 to the magnetic powder having the magnetic properties and used in Experiment 1. In summary, the magnetic properties (B_r and iH_c) and the Dy content rates of the first and second layers are as shown in the above-mentioned Table 8. In addition, although two kinds of powders are mixed and used for the second layer, one kind of magnetic powder having properties of $iH_c = 1.53 \text{ MA/m}$ and $B_r = 1.415 \text{ T}$ may also be prepared and used directly as a matter of course. The component composition at this time is a value obtained by adding all the components of the magnetic powder used in Experiment 2 and the magnetic

powder used in Experiment 1 and then by dividing the sum by two.

[Embodiment 16]

[0121]

Next, such a two-layer permanent magnet blank F as exemplified in Embodiment 10 will be described referring to FIG. 36 showing an example different from that shown in FIG. 35. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the two layers are formed while the first layer having a high intrinsic coercive force is extended at uneven intervals (at the 0.75T1 position) as shown in FIG. 36, irreversible demagnetization does not occur when the materials are selected such that the first layer has 1.85 MA/m and the second layer has 1.3775 MA/m.

As examples of the magnetic powders M being used for the above-mentioned first and second layers, those having the mixture ratios shown in Table 19 should be used. The magnetic properties (Br and iHc) and the Dy content rates of the first and second layers according to this embodiment are shown in Table 20.

[0122]

[Table 19]

	Mixture ratios of the magnetic powder M (%)		Thickness ratios of the respective layers (%)
	Magnetic powder M used in Experiment 2	Magnetic powder M used in Experiment 1	
High iHc compact element A side (1st layer)	100	0	75
High Br compact element B side (2nd layer)	25	75	25

[0123]

[Table 20]

	Br (T)	iHc (MA/m)	Dy content rate(mass%)
High iHc compact element A side(1st layer)	1.3600	1.8500	3.6
High Br compact element B side(2nd layer)	1.4425	1.3775	0.9
Permanent magnet	1.380625	—	2.925

However, the same effects are not obtained from the examples shown in FIGS. 35 and 36. The sum total of the areas of the triangles protruding upward (the areas of the shaded triangles) in FIG. 36 is larger. In other words, this means that the portion to which an excessive intrinsic coercive force is granted is large. When no triangles protruding downward are formed and when the sum total of the areas of the triangles protruding upward becomes smallest, the portion to which an excessive intrinsic coercive force is granted becomes smallest, whereby optimum design is attained. In the case that the distribution of the intrinsic coercive force changes linearly as shown in

FIG. 34, it is assumed to be optimal that the materials are selected such that the respective layers are divided at equal intervals, such that the intrinsic coercive force is not less than the required value and such that no excessive intrinsic coercive force is granted. For these reasons, in this case, the design shown in FIG. 35 is assumed to be optimal. However, in the case that there are limitations such that the optimal intrinsic coercive force cannot be selected because of difference in material availability or the like, it is expected that the effect of reducing the excessive intrinsic coercive force is obtained even if the layers are divided at uneven intervals, and it is thus worth attempting to apply such a division.

[0124]

Next, such a three-layer permanent magnet blank F as exemplified in Embodiment 11 will be described referring to FIG. 37. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the three layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first layer has 1.85 MA/m, the second layer has 1.64 MA/m and the third layer has 1.43 MA/m as shown in FIG. 37.

As examples of the magnetic powders M being used for the above-mentioned first to third layers, those having the

mixture ratios shown in Table 9 for example should be used.

The magnetic properties (B_r and iH_c) and the D_y content rates of the first to third layers according to this embodiment are shown in Table 10.

[0125]

Next, such a four-layer permanent magnet blank F as exemplified in Embodiment 12 will be described referring to FIG. 38. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the four layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first layer has 1.85 MA/m, the second layer has 1.6925 MA/m, the third layer has 1.535 MA/m and the fourth layer has 1.3775 MA/m as shown in FIG. 38.

As examples of the magnetic powders M being used for the above-mentioned first to fourth layers, those having the mixture ratios shown in Table 11 for example should be used. The magnetic properties (B_r and iH_c) and the D_y content rates of the first to fourth layers according to this embodiment are shown in Table 12.

[0126]

Next, such a five-layer permanent magnet blank F as exemplified in Embodiment 13 will be described referring to FIG. 39. With respect to the material properties of the

magnetic powders M according to this embodiment, in the case that the five layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first layer has 1.85 MA/m, the second layer has 1.724 MA/m, the third layer has 1.598 MA/m, the fourth layer has 1.472 MA/m and the fifth layer has 1.346 MA/m as shown in FIG. 39.

As examples of the magnetic powders M being used for the above-mentioned first to fifth layers, those having the mixture ratios shown in Table 13 for example should be used.

The magnetic properties (B_r and iH_c) and the Dy content rates of the first to fifth layers according to this embodiment are shown in Table 14.

[0127]

Next, such a ten-layer permanent magnet blank F as exemplified in Embodiment 14 will be described referring to FIG. 40. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the ten layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first to tenth layers have intrinsic coercive forces as shown in FIG. 40 and the above-mentioned Table 16.

As examples of the magnetic powders M being used for the above-mentioned first to tenth layers, those having the

mixture ratios shown in the above-mentioned Table 15 for example should be used. The magnetic properties (B_r and iH_c) and the Dy content rates of the first to tenth layers according to this embodiment are shown in Table 16.

[0128]

Next, such a 20-layer permanent magnet blank F as exemplified in Embodiment 15 will be described referring to FIG. 41. With respect to the material properties of the magnetic powders M according to this embodiment, in the case that the 20 layers are equally divided in the thickness direction, irreversible demagnetization does not occur when the materials are selected such that the first to 20th layers have intrinsic coercive forces as shown in FIG. 41 and the above-mentioned Table 18.

As examples of the magnetic powders M being used for the above-mentioned first to 20th layers, those having the mixture ratios shown in the above-mentioned Table 17 for example should be used. The magnetic properties (B_r and iH_c) and the Dy content rates of the first to 20th layers according to this embodiment are shown in Table 18.

[0129]

[Experiment 5]

Next, permanent magnets were produced so as to have the same magnetic properties at room temperature using Comparative Example 1 (the single-layer permanent magnet

blank F formed of the 100% magnetic powder M used in Experiment 1), Comparative Example 2 (the single-layer permanent magnet blank F formed of the 100% magnetic powder M used in Experiment 2), Embodiment 10, Embodiment 16 (the two-layer permanent magnet blank F), Embodiment 11 (the three-layer permanent magnet blank F), Embodiment 12 (the four-layer permanent magnet blank F), Embodiment 13 (the five-layer permanent magnet blank F), Embodiment 14 (the ten-layer permanent magnet blank F) and Embodiment 15 (the 20-layer permanent magnet blank F), and the working-effects obtained when the permanent magnets were placed in the same high-heat environment were summarized in Table 21.

More specifically, the permanent magnet blanks F having a thickness T_1 of 8 mm, a width W_1 of 40 mm and a length L_1 of 53.5 mm are obtained as exemplified; however, if these are magnetized directly, the residual magnetic flux density (B_r) of Comparative Example 1 is high and that of Comparative Example 2 is low, for example; hence, they are different in the amount of magnetic flux (flux value: weber (Wb) used as the unit) of the whole magnet, thereby being not the same in the magnetic properties. Generally, the weight (length) of the magnet is adjusted to align these. Hence, the permanent magnet blanks were ground in the length direction on the basis of Comparative Example 2 having the smallest B_r such that the flux values of the

magnetized permanent magnets have the same value. The lengths and weights obtained at this time are shown in Table 21. In addition, since the Dy content rates are as described earlier, the amount of use of Dy per permanent magnet is as shown in Table 21.

A flux meter was used to measure flux values. More specifically, the amount of the magnetic flux obtained from the potential difference at the time when a permanent magnet was placed in a coil and the permanent magnet was removed from the coil at constant speed was used as the flux value. Grinding was carried out little by little under cooling so that the internal tissue is not destroyed.

Demagnetization, grinding, remagnetization and flux value measurement were repeated until the flux values were aligned with the flux value of Comparative Example 2

Furthermore, the irreversible demagnetization state of the permanent magnet exposed to high heat, caused owing to heat, was observed. More specifically, two copper blocks, each having a structure capable of adjusting temperature and passing cooling water and also capable of heating using an electric heater and having a ground face capable of maintaining a constant temperature in the range of room temperature to approximately 300°C, were prepared, and the ground faces were disposed so as to be opposed to each other. A permanent magnet was held for one hour between

the ground faces in the thickness direction (such that the ground faces were made contact with the lengthwise faces of the permanent magnet having a width W_1 of 40 mm and the length obtained after grinding). Since the volume of the copper block was sufficiently larger than that of the permanent magnet, local temperature distribution was hardly generated. Moreover, a thermocouple was embedded in the contact section just under the copper block side, and the cooling water and the heater were controlled so that a preset surface temperature was maintained. Still further, heat conductive grease was used on the ground faces to facilitate heat conduction to the permanent magnet.

The temperature of the copper block on the low-temperature side was set at 65°C , and the temperature on the high-temperature side was set at 155°C . A thermocouple was inserted into the permanent magnet, and the temperature distribution in the thickness direction was examined, and it was verified that the temperature changed linearly from the high-temperature side to the low-temperature side. Since a temperature gap was generated on the contact faces, the surface temperature of the permanent magnet was 70°C at the contact face on the low-temperature side and 150°C at the contact face on the high-temperature side.

A high-heat environmental test was conducted using the above-mentioned method while temperature distribution was

generated inside the permanent magnet, and the permanent magnet was removed from between the copper blocks and allowed to slowly cool to room temperature. Then, the flux value was just measured using the flux meter; the value obtained by dividing the flux value with the flux value of Comparative Example 2 before the high-heat environmental test is shown in Table 21. Since the flux value lowers if irreversible demagnetization occurs, the value was used as an index indicating the degree of irreversible demagnetization. The value in Table 21 being closer to 1.0 indicates that irreversible demagnetization has not occurred, and the value being smaller indicates that the degree of irreversible demagnetization is large.

[0130]

As a result, the Br of the magnet according to Comparative Example 1 is high, the weight of the magnet can be reduced, and the amount of use of Dy is zero; however, if the magnet is exposed to a high-heat environment, it is demagnetized significantly, and its initial magnetic properties cannot be maintained. The Br of the magnet according to Comparative Example 2 is low, and both the weight and the amount of use of Dy of the magnet are large although irreversible demagnetization does not occur, whereby the magnet is most expensive in cost. Even when the magnets according to Embodiments 10 to 16 are exposed

to a high-heat environment having temperature distribution, irreversible demagnetization does not occur. Furthermore, as the number of layers is larger, Br becomes higher and the magnet weight and the amount of use of Dy become lower.

However, as the number of layers is larger, time and effort for producing a composite compact are increased, resulting in raising cost. The number of layers should only be determined on the basis of the requested cost and performance of the magnet. In any case, the magnets according to Embodiments 10 to 16 are permanent magnets being excellent in magnetic properties and have an effect capable of being used for a long life period under a high-heat environment.

Furthermore, since the magnets according to Embodiments 10 to 16 can also be reduced in length in comparison with the magnet according to Comparative Example 2, the volume of an apparatus in which the permanent magnet is built in can be reduced by that amount, this being a merit to be written additionally.

Ease of measurement, ease of application of a load to the permanent magnet and the irreversible demagnetization state of the permanent magnet placed in an environment exposed to high heat were examined as described above, and similar working-effects were obtained even when magnetic field distribution was provided by applying an external

demagnetizing field to the permanent magnet and even when the permanent magnet was simultaneously exposed to a high-heat environment and an external demagnetizing field environment. The intrinsic coercive force distribution requested for the magnet should be obtained from the temperature distribution and the magnetic field intensity distribution, and the design should only be carried out so as to conform to the distribution.

[0131]

[Table 21]

	Br (T)	Length of the permanent magnet after grinding (mm)	Weight of the permanent magnet after grinding (g)	Dy content rate (mass%)	Amount of use of Dy (g)	Flux value rate (※1)	
						After grinding, demagnetization, remagnetization	After high-heat environmental exposur
Comparative Example 1	1.4700	49.40	120.9	0	0.00	1.0	0.63
Comparative Example 2	1.3600	53.40	130.7	3.6	4.71	1.0	1.0
Embodiment 10	1.3875	52.34	128.1	2.7	3.46	1.0	1.0
Embodiment 16	1.3806	52.60	128.8	2.93	3.77	1.0	1.0
Embodiment 11	1.3970	51.99	127.3	2.4	3.05	1.0	1.0
Embodiment 12	1.4013	51.83	126.9	2.25	2.85	1.0	1.0
Embodiment 13	1.4040	51.73	126.6	2.16	2.74	1.0	1.0
Embodiment 14	1.4095	51.52	126.1	1.98	2.50	1.0	1.0
Embodiment 15	1.4123	51.42	125.9	1.89	2.38	1.0	1.0

※1: The ratio based on the flux value before high-heat environmental exposure of a comparative example 2

[Embodiment 17]

[0132]

Next, an example is shown in which the composite compact E shown in FIG. 42 is different from the composite compact E shown in FIG. 13(c2) in that one high iHc compact element A or one high Br compact element B is added.

In FIG. 42, the high iHc compact element A and the high Br compact element B are formed using a means similar to that described referring to FIG. 17, whereby a configuration is attained such that functions, properties, characteristics, etc. similar to those of them are obtained.

Next, A2 shown in FIG. 42(a) designates a high iHc compact element provided symmetrically with the high iHc compact element A as shown in the figure. The composition of the high iHc compact element A2 should only be made similar to that of the high iHc compact element A.

Next, the means of forming the composite compact E formed of the high iHc compact element A, the high Br compact element B and the high iHc compact element A2 shown in FIG. 42(a) should only be used according to a concept similar to that of the means of forming the composite compact E obtained by combining and integrating three layers as described referring to FIG. 24. Furthermore, the composite compact E is subjected to plastic working to form a permanent magnet blank F. As plastic working, the above-

mentioned various plastic working should only be used.

[0133]

Next, B2 shown in FIG. 42(b) designates a high Br compact element provided symmetrically with the high Br compact element B as shown in the figure. The composition of the high Br compact element B2 should only be similar to that of the high Br compact element B.

The means of forming the composite compact E formed of the high Br compact element B, the high iHc compact element A and the high Br compact element B2 shown in FIG. 42(b) should only be used according to a concept similar to that of the means of forming the composite compact E obtained by combining and integrating three layers as described referring to FIG. 24. Furthermore, the composite compact E is subjected to plastic working to form a permanent magnet blank F. As plastic working, the above-mentioned various plastic working should only be used.

[0134]

Next, the necessity of the various types of permanent magnet blanks F and the like formed of multiple layers shown in FIG. 42 are as described below.

When a permanent magnet actually built in a magnet circuit is considered, the intrinsic coercive force distribution inside the permanent magnet is not simply high on one side and low on the other side, but the intrinsic

coercive force distribution is generally more complicated. For example, since an electric motor is used in both forward and reverse rotation directions, a pattern in which the intrinsic coercive force is high at both end portions and low at the central portion is considered in order to conform to this (see FIG. 42(a)). In addition, in another magnetic circuit, conversely, a pattern in which the intrinsic coercive force is low at both end portions and high at the central portion is possible (see FIG. 42(b)).

Even in these cases, with the method according to this embodiment, without using a permanent magnet being difficult to produce and high in cost, containing a large amount of expensive Dy or the like and having a high intrinsic coercive force and a high residual magnetic flux density, it is possible to provide a permanent magnet being easy to produce and low in cost and containing a scarce amount of Dy or the like. In other words, this can be attained by appropriately disposing a member having a high intrinsic coercive force and a low residual magnetic flux density (for example, a member formed of the magnetic powder M used in the above-mentioned Experiment 2) and a member having a low intrinsic coercive force and a high residual magnetic flux density (for example, a member formed of the magnetic powder M used in the above-mentioned Experiment 1) so as to conform to the intrinsic coercive

force distribution. The pattern of member disposition and the number of layers should only be determined in consideration of the balance between cost and effect.

FIG. 42(a) shows an example of a three-layer structure featuring a high intrinsic coercive force, a low intrinsic coercive force and a high intrinsic coercive force in the Y-direction so as to conform to the intrinsic coercive force disposition inside the permanent magnet used for an electric motor. Since a material having a high residual magnetic flux density can be used at the lower intrinsic coercive force portion, the whole permanent magnet can have a residual magnetic flux density higher than that of a permanent magnet formed of a single member having a high intrinsic coercive force. Furthermore, although one layer is used in the X-direction in this example, if the intrinsic coercive force distribution in this direction is also large, by further increasing the number of the layers to two or three in the X-direction, it is possible to obtain a permanent magnet comprising portions having intrinsic coercive forces conforming to the required intrinsic coercive force distribution, scarcely having wastefully high intrinsic coercive forces, and having high residual magnetic flux densities. At the same time, the amount of use of Dy or the like is reduced in comparison with the permanent magnet formed of only a single member

having a high intrinsic coercive force.

For example, if the intrinsic coercive force on the front side is requested to be higher than that on the rear side in FIG. 42(c), the intrinsic coercive forces should be selected such that $A > A'$, $B > B'$ and $B_2 > B_2'$. The concept shown in FIG. 34 is extended and used as a selection method in which the intrinsic coercive forces requested in a three-dimensional graph indicating the intrinsic coercive force, thickness and width are plotted in three dimensions and materials are selected such that the portions (volumes in three dimensions) having excessive intrinsic coercive forces are minimized, whereby the residual magnetic flux density B_r can be raised and the amounts of use of the magnet and Dy or the like can be reduced without causing irreversible demagnetization.

[Brief Description of the Drawings]

[0135]

FIG. 1 is a schematic view illustrating a method of producing a permanent magnet blank;

FIG. 2(a) is a vertical sectional front view illustrating an extrusion die being used for extrusion serving as plastic working, and FIG. 2(b) is a vertical sectional side view illustrating the extrusion die;

FIG. 3 is an enlarged vertical sectional front view illustrating a forming die in the extrusion die;

FIG. 4 is an enlarged vertical sectional side view illustrating the forming die in the extrusion die;

FIG. 5 is a plan view illustrating the forming die in the extrusion die;

FIG. 6 is a bottom view illustrating the forming die in the extrusion die;

FIG. 7 is a schematic perspective view illustrating the state of plastic working in which a permanent magnet blank is extruded from a high-density element using the extrusion die at the time of extrusion;

FIG. 8 is a view illustrating plastic working in FIGS. 1(c) and 1(d), FIG. 8(a) is a schematic perspective view showing a high-density element, and FIG. 8(b) is a schematic perspective view showing a permanent magnet blank produced by subjecting the high-density element to extrusion;

FIG. 9 is a schematic perspective view illustrating examples different from the high-density element and the permanent magnet blank F shown in FIGS. 1 to 8;

FIG. 10 is a schematic plan view illustrating an example different from the forming die in the extrusion die shown in FIGS. 2 to 6;

FIG. 11 is a schematic perspective view illustrating examples different from the high-density element and the permanent magnet blank F shown in FIGS. 1 to 8;

FIG. 12 is a schematic perspective view illustrating examples different from the high-density element and the permanent magnet blank F shown in FIGS. 1 to 8;

FIG. 13 is a schematic view illustrating a method of producing a permanent magnet blank (two-element permanent magnet blank);

FIG. 14 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 1;

FIG. 15 is a schematic view illustrating a process different from the process for the composite compact E shown in FIGS. 13(a) to 13(c2);

FIG. 16 is a schematic view illustrating a process different from the process for the composite compact E shown in FIGS. 13(a) to 13(c2);

FIG. 17 is a schematic view illustrating an example different from the composite compact E shown in FIG. 13(c2) in the direction in which a high iH_c compact element and a high B_r compact element are combined and in the flattening direction in plastic working;

FIG. 18 is a schematic view illustrating a process different from the process for the composite compact E shown in FIGS. 17(a) to 17(c2);

FIG. 19 is a schematic view illustrating a process different from the process for the composite compact E shown in FIGS. 17(a) to 17(c2);

FIG. 20 is a schematic perspective view illustrating examples different in shape from the composite compact E and the permanent magnet blank F shown in FIG. 13;

FIG. 21 is a schematic perspective view illustrating examples different in shape from the composite compact E and the permanent magnet blank F shown in FIG. 13;

FIG. 22 is a schematic perspective view illustrating examples different in shape from the composite compact E and the permanent magnet blank F shown in FIG. 13;

FIG. 23 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 10;

FIG. 24 is a schematic view illustrating a method of producing a permanent magnet blank (three-element permanent magnet blank);

FIG. 25 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 11;

FIG. 26 is a schematic view illustrating a method of producing a permanent magnet blank (four-element permanent magnet blank);

FIG. 27 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 12;

FIG. 28 is a schematic view illustrating a method of producing a permanent magnet blank (five-element permanent magnet blank);

FIG. 29 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 13;

FIG. 30 is a schematic view illustrating a method of producing a permanent magnet blank (ten-element permanent magnet blank);

FIG. 31 is a graph showing the relationship between the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank according to Embodiment 14;

FIG. 32 is a graph showing the relationship between

the residual magnetic flux density (B_r) and the intrinsic coercive force (iH_c) of a permanent magnet obtained by magnetizing the permanent magnet blank (11-element permanent magnet blank) according to Embodiment 15;

FIG. 33 is a view illustrating an example in which a high iH_c compact element, multiple intermediate compact elements and a high B_r compact element are combined and integrated at the time when the elements are powder elements, FIG. 33(A) is a view illustrating a method of forming a permanent magnet blank by combining multiple powder elements being mutually different in material properties, and FIG. 33(B) is an end view taken along line S-S in (a) of FIG. 33(A);

FIG. 34 is a graph illustrating an example for selecting the material properties of the magnetic powder M and showing the intrinsic coercive force distribution requested in the thickness direction;

FIG. 35 is a graph illustrating an example (two-layer) for selecting the material properties of the magnetic powder M;

FIG. 36 is a graph illustrating an example (two-layer) for selecting the material properties of the magnetic powder M;

FIG. 37 is a graph illustrating an example (three-layer) for selecting the material properties of the

magnetic powder M;

FIG. 38 is a graph illustrating an example (four-layer) for selecting the material properties of the magnetic powder M;

FIG. 39 is a graph illustrating an example (five-layer) for selecting the material properties of the magnetic powder M;

FIG. 40 is a graph illustrating an example (ten-layer) for selecting the material properties of the magnetic powder M;

FIG. 41 is a graph illustrating an example (20-layer) for selecting the material properties of the magnetic powder M; and

FIG. 42 is a schematic view illustrating an example different from the composite compact E shown in FIG. 13(c2).

[Document Name] CLAIMS

1. A method of producing a composite compact for a permanent magnet by combining and integrating:

a high iH_c compact element that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high B_r compact element and being low in residual magnetic flux density in comparison with said high B_r compact element and

said high B_r compact element that is formed of a magnetic powder being high in residual magnetic flux density in comparison with said high iH_c compact element and being low in intrinsic coercive force in comparison with said high iH_c compact element.

2. A method of producing a composite compact for a permanent magnet by combining and integrating:

a high iH_c compact element that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high B_r compact element and being low in residual magnetic flux density in comparison with said high B_r compact element,

said high B_r compact element that is formed of a magnetic powder being high in residual magnetic flux density in comparison with said high iH_c compact element and being low in intrinsic coercive force in comparison

with said high iHc compact element, and

an intermediate compact element formed of a magnetic powder used for said intermediate element,

in a state in which said intermediate compact element is disposed between said high iHc compact element and said high Br compact element, wherein

material properties of said magnetic powder used for said intermediate compact element in the combined and integrated state of said composite compact are set to properties such that

the intrinsic coercive force becomes lower sequentially in the direction from said high iHc compact element to said high Br compact element and such that

the residual magnetic flux density becomes lower sequentially in the direction from said high Br compact element to said high iHc compact element.

3. A method of producing a composite compact for a permanent magnet by combining and integrating:

a high iHc compact element that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high Br compact element and being low in residual magnetic flux density in comparison with said high Br compact element,

said high Br compact element that is formed of a

magnetic powder being high in residual magnetic flux density in comparison with said high iHc compact element and being low in intrinsic coercive force in comparison with said high iHc compact element, and

multiple intermediate compact elements formed of multiple magnetic powders used for said intermediate elements and different mutually in material properties,

in a state in which said multiple intermediate compact elements are disposed between said high iHc compact element and said high Br compact element, wherein

the respective material properties of said respective magnetic powders used for said multiple intermediate compact elements in the combined and integrated state of said composite compact are set to properties such that

the respective intrinsic coercive forces become lower sequentially in the direction from said high iHc compact element to said high Br compact element and such that

the respective residual magnetic flux densities become lower sequentially in the direction from said high Br compact element to said high iHc compact element.

4. A method of producing a composite compact for a permanent magnet by combining:

a high iHc powder element that is formed of a magnetic powder being high in intrinsic coercive force in comparison

with a high Br powder element and being low in residual magnetic flux density in comparison with said high Br powder element,

said high Br powder element that is formed of a magnetic powder being high in residual magnetic flux density in comparison with said high iHc powder element and being low in intrinsic coercive force in comparison with said high iHc powder element and

multiple intermediate powder elements formed of multiple magnetic powders used for said intermediate elements and different mutually in material properties,

in a state in which said powder elements are arranged mutually in parallel inside a cavity and,

in a state in which said multiple intermediate powder elements are disposed between said high iHc powder element and said high Br powder element, and

by integrating said powder elements using pressing means to form said composite compact, wherein

the material properties of said respective magnetic powders used for said multiple intermediate powder elements are set to properties in the combined and integrated state of said compact element such that

the respective intrinsic coercive forces become lower sequentially in the direction from said high iHc compact element to said high Br compact element and such that

the residual magnetic flux densities become lower sequentially in the direction from said high Br compact element to said high iHc compact element.

5. A method of producing a permanent magnet blank by combining and integrating:

a high iHc compact element that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high Br compact element and being low in residual magnetic flux density in comparison with said high Br compact element and

said high Br compact element that is formed of a magnetic powder being high in residual magnetic flux density in comparison with said high iHc compact element and being low in intrinsic coercive force in comparison with said high iHc compact element to form a composite compact, and

by subjecting said composite compact to plastic working to provide magnetic anisotropy,

said plastic working being extrusion that is used to extrude said composite compact into a permanent magnet blank having a predetermined shape, wherein

an extrusion direction at a time of said extrusion is parallel with an alignment face of said high Br compact element and said high iHc compact element of said composite

compact,

a direction of flattening said composite compact is perpendicular to said alignment face, and

easy axes of magnetization of said permanent magnet blank are oriented in said direction perpendicular to said alignment face.

6. A method of producing a permanent magnet blank by combining and integrating:

a high iH_c compact element that is formed of a magnetic powder being high in intrinsic coercive force in comparison with a high B_r compact element and being low in residual magnetic flux density in comparison with said high B_r compact element and

said high B_r compact element that is formed of a magnetic powder being high in residual magnetic flux density in comparison with said high iH_c compact element and being low in intrinsic coercive force in comparison with said high iH_c compact element to form a composite compact, and

by subjecting said composite compact to plastic working to provide magnetic anisotropy,

said plastic working being extrusion that is used to extrude said composite compact into a permanent magnet blank having a predetermined shape, wherein

an extrusion direction at a time of said extrusion is parallel with an alignment face of said high Br compact element and said high iHc compact element of said composite compact,

a direction of flattening said composite compact is parallel with said alignment face and perpendicular to said extrusion direction, and

easy axes of magnetization of said permanent magnet blank are oriented in said direction parallel with said alignment face and in said direction perpendicular to said extrusion direction.