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(54) Method for producing selected grades of rare earth magnets using a plurality of particle batches

(57) A method for producing selected grades of rare earth element containing permanent magnets. A plurality of particle batches of rare earth element containing permanent magnet alloys are produced with each having a different chemical composition and different magnetic properties. These batches are blended in varying amounts to achieve particle mixtures that when processed to produce magnets will exhibit selected combinations of magnetic properties different from those of each particle batch and different from each other mixture. Selected mixtures are used to produce a selected grade of a rare earth element containing permanent magnet.

Variation of Br and Hci vs Dy content

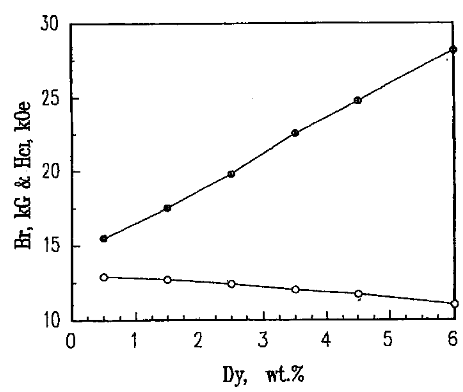

Figure 1

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to a method for producing selected grades of rare earth element containing permanent magnets by admixing or blending a plurality of batches of rare earth element containing permanent magnet alloys with each of the batches having a different chemical composition and different magnetic properties. With this practice, various grades of rare earth element containing permanent magnets may be produced without requiring the production of a specific alloy corresponding to each of the grades to be produced.

Description of the Prior Art

It is known to produce permanent magnet alloys, and magnets produced therefrom, containing rare earth elements, and specifically having a rare earth element content in combination with a transition element, namely iron, and boron.

Magnets of this type are used in various applications, including electric motors, loudspeakers, imaging devices, and the like. As a result of the many and varied applications for these rare earth element magnets, it is necessary to produce many grades of the magnets having desired combinations of magnetic properties for the various specific applications in which they are used. In this regard, to reduce the cost of the final product with which these magnets are employed, it is desirable to maintain the number of alloy compositions melted at a minimum. Conventionally, this has been impossible to achieve, because the required combination of magnetic properties for the many magnet grades required to satisfy the many and varied applications for these magnets has required the melting of specific alloy compositions for each required grade. Specifically, to this end, it is conventional practice to produce specific alloy compositions for each magnet grade to be produced. The alloy for each magnet grade has the alloying constituents thereof present in amounts necessary to achieve the desired properties in the magnet for the intended application. This production and inventory of a specific alloy for each magnet grade to be produced adds considerably to the final cost of the magnets and thus the products with which they are employed.

SUMMARY OF THE INVENTION

In accordance with the invention, the method thereof provides for producing selected grades of a rare earth element containing permanent magnet by producing a plurality of particle batches of rare earth element containing permanent magnet alloys, with each of the batches having a different chemical composition and different permanent magnet properties. The batches are blended in varying amounts to achieve particle mixtures each having selected different compositions which has been determined that when processed to produce a permanent magnet will exhibit selected combinations of permanent magnet properties different from permanent properties of permanent magnets produced from each batch and different from each of the other mixtures. One of these mixtures is then processed in any conventional manner to produce the desired, selected grade of rare earth element containing permanent magnet therefrom. The processing may include sintering. With respect to blending of the plurality of particle batches, this may be achieved by a practice including selectively increasing the heavy rare earth element content of the resulting mixture to increase intrinsic coercivity and correspondingly decrease remanence and energy product and vice versa, with respect to the desired grade of magnet to be produced from the blended particle batch.

It is accordingly a primary advantage of the present invention to provide a method for producing rare earth element containing permanent magnets wherein various grades of permanent magnets may be produced without requiring the production of a specific alloy for each grade of magnet.

A more specific advantage of the invention is to provide a method for producing rare earth element containing permanent magnets wherein the combination of desired magnetic properties may be varied to produce various magnet grades by a practice that includes blending or admixing a plurality of particle batches of different permanent magnet alloy compositions to achieve a final magnet composition that will result in the desired combination of magnetic properties.

At least one of the permanent magnet alloys of the particle batches preferably has a heavy rare earth element and a light rare earth element. The heavy rare earth element may be Dy and the light rare earth element may be Nd. The heavy rare earth elements Ho and Tb may also be present.

The plurality of particle batches may be of the composition having a rare earth element content, a transition metal, and boron. The total rare earth element content may be 25 to 40%, with Nd being greater than 50% of the total rare earth element content, up to 15% of at least one heavy rare earth element of Tb, Ho and Dy, 40 to 75% total transition element content, with Fe being 30 to 100% of the total transition element content, Co up to 20%, 0.8 to 1.5% B, and up to 20% of at least one of Al, Cu, Ag, Ga, Sn, Nb, W, Mo, Cr, V, Ti, and Zn. Each of the batches may have a different rare earth element content and different permanent magnet properties.

Preferably two particle batches may be used for blending to achieve the particle mixture. When two particle batches are used for blending, one particle batch may have a heavy rare earth element content of up to 7% and the second particle batch may have a heavy rare earth element content of 4 to 15%. The heavy rare earth element content may be Dy, Tb, or Ho. Each of these may have the same or varying amounts of the above-listed elements.

When three particle batches are employed for blending, the total rare earth element content of one batch may be 26 to 32% with a heavy rare earth element content of up to 7%, a second particle batch may have a total rare earth element content of 30 to 34% with a heavy rare earth element content of up to 7%, and the third particle batch may have a total rare earth element content of 30 to 36% with a heavy rare earth element content of 4 to 15%.

There now follows a description of preferred embodiments of the invention, by way of non-limiting example, with reference being made to the accompanying drawings in which:

Figure 1 is a graph showing that as the Dy content and total rare earth element content increases, the intrinsic coercivity almost linearly increases and the remanence almost linearly decreases; and
Figure 2 is a similar graph showing that as the Dy content and total rare earth element content increases, the energy product almost linearly decreases.

Sintered magnets have been made by conventional powder metallurgy processing from either cast ingots or atomized powder. The predetermined alloy compositions are melted in an inert gas atmosphere and the melt is poured into a metallic mold to make cast ingots or alternately is atomized into powders by the use of inert gas. With ingot production, the ingots are coarsely crushed. With both practices, either the coarse particles or atomized powders may be exposed to a hydrogen atmosphere for hydrogen decrepitation. The coarse hydrogen decrepitated particles are further ground, as by milling, into fine powders with particle sizes ranging from about 1 to 20 microns. The fine particles are magnetically aligned and compacted. The resulting compacts are then sintered at temperatures between 900 and 1200°C and aged at 400 to 700°C. The fully densified magnets resulting from this operation are then machined to final shape and coated with a corrosion protection layer. In accordance with this conventional practice, the magnets are generally prepared directly from a single alloy.

No matter how the single alloys are prepared, an inventory of specific alloys each corresponding to a specific grade is produced and inventoried for magnet production.

In accordance with the invention, a plurality of alloys and specifically preferably two alloys, may be prepared and blended to achieve various alloys suitable for desired grades of permanent magnets, each exhibiting different combinations of magnetic properties suitable for use in the manufacture of specific final products.

<u>Specific Examples</u>

Two alloys were prepared in a vacuum induction melting furnace and atomized into powders. Their alloy compositions (by wt.%) are listed in Table 1:

Table 1

	TRE	Nd	Dy	Fe	Co	B	Cu	Nb	Al
A:	32	31.5	0.5	65.65	1.2	1.0	0.15	-	-
B:	34	28	6	61.3	2.5	1.1	0.15	0.65	0.3
(TRE means total rare earth element content.)									

The Table 1 alloys were hydrided and jet milled into powders having average particle size of one to five microns. The milled powders were blended into the predetermined ratios as listed in Table 2.

Table 2

Blends A:B	Controlled Alloy Chemistries (Wt.%)							
	TRE	Dy	Fe	Co	B	Cu	Nb	Al
100:0	32	0.5	65.65	1.2	1.0	0.15	0	0
81.8:18.2	32.36	1.5	64.86	1.44	1.018	0.15	0.118	0.054
63.6:36.4	32.73	2.5	64.07	1.67	1.036	0.15	0.236	0.108
45.4:54.6	33.09	3.5	63.27	1.91	1.054	0.15	0.355	0.163
27.3:72.7	33.45	4.5	62.49	2.15	1.072	0.15	0.473	0.216
0:100	34	6.0	61.3	2.5	1.1	0.15	.065	0.3

The blends were put into the rubber molds, magnetically aligned, and cold isostatically pressed. The pressed compacts were sintered in a vacuum furnace at 1050°C for 1.5 hours and aged at 520°C for one hour.

The magnetic properties of those blends are listed in Table 3:

Table 3

Blends		Wt.%		Magnetic Properties		
%A Alloy	%B Alloy	TRE	Dy	B_r kG	BH_{max} MGOe	H_{ci} kOe
100.00	0.0	32.00	0.50	12.90	40.00	15.50
81.80	18.20	32.36	1.50	12.70	38.90	17.50
63.60	38.40	32.73	2.50	12.40	37.80	19.80
45.40	54.60	33.09	3.50	12.00	35.00	22.55
27.30	72.70	33.45	4.50	11.70	33.30	24.75
0.0	100.00	34.00	6.00	11.00	30.00	28.15

As shown in this table, many grades of magnets are generated by blending two master alloys A and B.

The magnetic properties are also plotted against Dy content in Figures 1 and 2.

As shown in Table 3 and Figures 1 and 2, as the Dy and TRE contents increase, the H_{ci} almost linearly increases and the B_r and BH_{max} almost linearly decrease. This indicates that various grades of magnets can be formulated and produced within the specified (upper and lower) limits by blending these two alloys. In other words, many magnet grades can be produced with only two master alloys. Therefore, the inventory of master alloys can be reduced to two from the many alloys corresponding to the number of magnetic grades to be produced. This significantly reduces the inventory cost and improves the efficiency of production.

It is also noted that the magnets from the blended alloys exhibit slightly higher B_r and BH_{max} than the predicted values (or single alloys), while the H_{ci} of those coincide to the predicted values.

Therefore, the magnets produced from the blends of two master alloys exhibit equal or improved magnet properties compared to magnets made from the single alloys.

The term "grade" as used herein means a chemical composition of a finished magnet with selected, defined magnet properties.

As used herein, all percentages are in "weight percent," unless otherwise indicated.

The following conventional abbreviations are used herein:

B_r - remanence
H_{ci} - intrinsic coercivity
BH_{max} - maximum energy product
T_c - Curie temperature
TRE - total rare earth element(s)

Claims

1. A method for producing selected grades of rare earth element containing permanent magnets, said method comprising producing a plurality of particle batches of rare earth element containing permanent magnet alloys with each of said batches having a different chemical composition and different permanent magnet properties, blending said batches in varying amounts to achieve particle mixtures having selected different compositions that when processed to produce a permanent magnet will exhibit selected combinations of permanent magnet properties different from permanent magnet properties of permanent magnets produced from each of said plurality of particle batches individually and different from each other mixture, and processing one of said mixtures having a selected composition to produce a selected grade of a rare earth element containing permanent magnet therefrom.

2. The method of claim 1, wherein at least one of said permanent magnet alloys of said particle batches comprises a heavy rare earth element and a light rare earth element.

3. The method of claim 2, wherein said heavy rare earth element comprises Dy and said light rare earth element comprises Nd.

4. The method of claim 2 or 3, wherein said plurality of particle batches is blended to achieve said particle mixture with said heavy rare earth element thereof being selectively increased to achieve increased intrinsic coercivity and decreased remanence and energy product and vice versa.

5. The method of claim 2 or any claim dependent therefrom, wherein said plurality of particle batches constitutes two rare earth element containing permanent magnet alloys with one of said particle batches having a higher rare earth element content than another of said particle batches.

6. The method of claim 3 or any claim dependent therefrom, wherein said rare earth element content further comprises at least one heavy rare earth element of Dy, Ho, or Tb in combination with said Nd.

7. The method of any of claims 2 to 6, wherein at least one of said permanent magnet alloys of said plurality of particle batches comprises Nd, Fe, and B.

8. The method of claim 7, wherein said at least one of said permanent magnet alloys further includes Dy.

9. A method for producing selected grades of rare earth element, transition metal, and boron permanent magnets, said method comprising producing a plurality of particle batches of rare earth element, transition metal, and boron permanent magnet alloys with each of said batches consisting essentially of, in weight percent, 25 to 40 total rare earth element content, up to 15 of at least one heavy rare earth element of Ho, Tb and Dy, 40 to 75 total transition element content, with Fe being 30 to 100% of the total transition element content, Co up to 20, 0.8 to 1.5 B, and up to 20 of at least one of Al, Cu, Ag, Ga, Sn, Nb, W, Mo, Cr, V, Ti, and Zn, and each of said batches having a different rare earth element content and different permanent magnet properties, blending said batches in varying amounts to achieve particle mixtures having selected different compositions that when processed to produce a permanent magnet will exhibit a selected combination of permanent magnet properties different from the permanent magnet properties of permanent magnets produced from each of said plurality of particle batches individually and different from each other mixture and processing one of said mixtures having a selected composition to produce a selected grade of a rare earth element containing permanent magnet therefrom.

10. The method of claim 9, wherein at least one of said permanent magnet alloys of said particle batches includes at least one of said heavy rare earth elements Ho, Tb and Dy.

11. The method of claim 10, wherein said heavy rare earth element comprises Dy and wherein said alloy includes a light rare earth element comprising Nd.

12. The method of any of claims 9 to 11, wherein said plurality of particle batches is blended to achieve said particle mixture with said heavy rare earth element content thereof being selectively increased to achieve increased intrinsic coercivity and decreased remanence and energy product and vice versa.

13. The method of any of claims 10 to 12, wherein said plurality of particle batches constitutes two rare earth element containing permanent magnet alloys with one of said particle batches having a higher rare earth element content than another of said particle batches.

14. The method of any of claims 10 to 13, wherein said rare earth element content of at least one of Dy, Ho and Tb is in combination with Nd.

15. The method of any of claims 10 to 14, wherein at least one of said permanent magnet alloys of said plurality of particle batches comprises Nd, Fe and B.

16. The method of claim 15, wherein said at least one of said permanent magnet alloys further includes Dy.

17. The method of any of claims 1, 2, 9 or 10, wherein said plurality of particle batches is more than two.

18. The method of claim 17, wherein said plurality of particle batches includes one particle batch having a heavy rare earth element content of up to 7 and a second particle batch having a heavy rare earth element content of 4 to 15.

19. The method of claim 18, wherein the heavy rare earth element content is at least one of Ho, Dy and Tb.

20. The method of any of claims 17 to 19, wherein said plurality of particle batches includes one particle batch having a total rare earth element content of 26 to 32 with a heavy rare earth element content of up to 7, a second particle batch having a total rare earth element content of 30 to 34 with a heavy rare earth element content of up to 7, and a third particle batch having a total rare earth element content of 30 to 36 with a heavy rare earth element content of 4 to 15.

21. The method of any preceding claim, wherein said processing includes sintering.

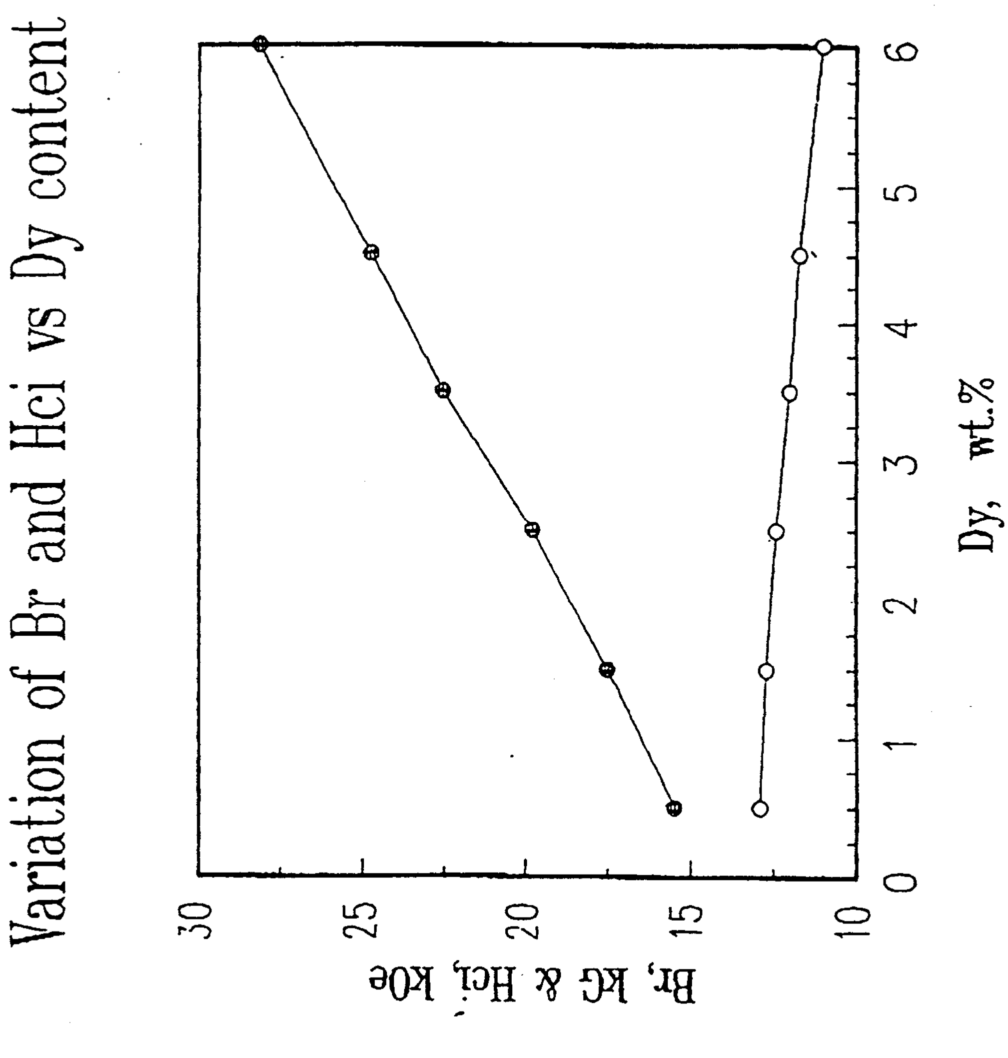
Variation of Br and Hci vs Dy content
Br, kG & Hci, kOe
30
25
20
15
10
Dy, wt.%
0
1
2
3
4
5
6

Figure 1

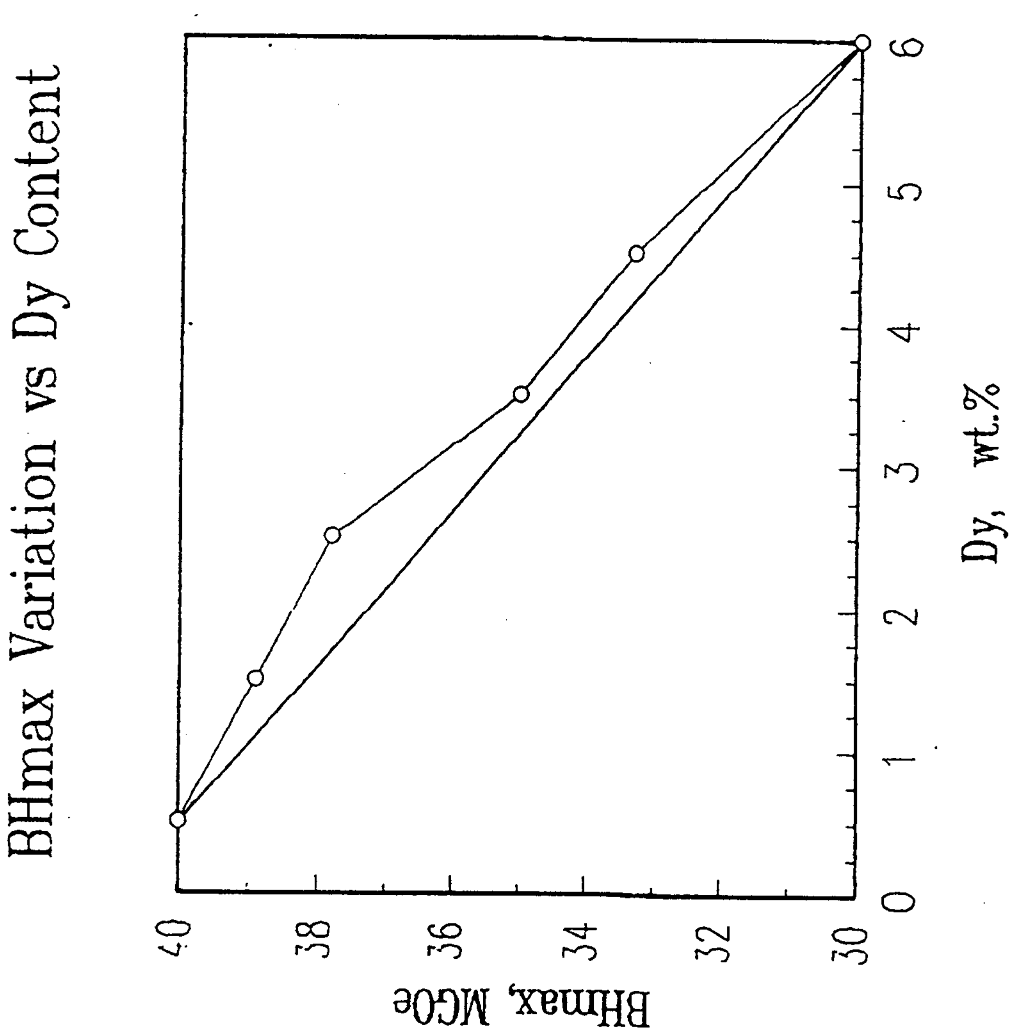
BHmax Variation vs Dy Content
BHmax, MGOe
40
38
36
34
32
30
0
1
2
3
4
5
6
Dy, wt.%

Figure 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 8727

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP 0 601 943 A (UGIMAG SA) 15 June 1994 * page 4, line 12 - line 17; claims 1,6,7,14,17,19,21,26; example 1; tables 1,2,4,11,12 *	1-17	H01F1/055 H01F1/057 H01F41/02
X	EP 0 561 650 A (SUMITOMO SPEC METALS) 22 September 1993 * claims 1,16,20,21; tables 1-4 *	1-16,21	
A	E.WOLFARTH ET AL: "Ferromagnetic Materials Vol 4" 1988 , ELSEVIER , AMSTERDAM NL XP002032140 * page 95, paragraph 3 *	1-3,5-7	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	2 June 1997	Decanniere, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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E : earlier patent document, but published on, or after the filing date
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