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## Description

The present invention relates to magnetic alloys and to a method of making same.

More particularly the invention relates to ternary magnetic alloys of the type consisting of rare-earth or rare-earth-like elements, cobalt and at least one metal selected from the group which consists of iron, nickel, aluminium, chromium, copper, molybdenum or manganese, which are adapted for realizing permanent magnets of improved mechanical properties, such as ductility and toughness in use or fabrication.

Ferromagnetic alloys of the cobalt/rare-earth type have a high energy product and for this reason have been widely used. At present they are generally fabricated by powder metallurgy, i.e. by sintering, high-pressure pressing or the like techniques.

The alloys generally have the formula $TRCo_y$, where TR is a rare-earth element such as samarium (Sm), gadolinium (Gd), praseodymium (Pr), cerium (Ce), neodymium (Nd), holmium (Ho) or an element similar to a rare-earth such as lanthanum (La) or yttrium (Y) or a mixture of such elements, y varies between 5 and 8.5.

Although these materials are remarkable for their magnetic properties, having a high intrinsic coercive force, of say, 25 kiloOersted (kOe) and a high saturation magnetization of, say, 10 kiloGauss (kG), resulting in a high energy product, they are extremely fragile, difficult to work and sensitive to environmental conditions. Because of these shortcomings, the fabrication of small magnets by machining is difficult. When attempts are made to fabricate large magnets, it is found that the bodies tend to break during fabrication because of internal stresses.

Alloys containing copper as well as $TRc_y$ which are prepared by casting have also been proposed heretofore. These alloys are subjected to a magnetic hardening treatment but are also found to be very brittle and difficult to work, particularly by turning and similar machining operations.

Swiss Patent Nr. 601 481 discloses magnetic alloys having the formula $TR(CO,X)_y$ wherein X is at least one metal selected from the groups comprising iron, nickel, copper, aluminium, molybdenum and manganese. TR is present in an amount of 5 to 22,5% (atomic) of the alloy, X varies between 5 and 65% (atomic) of the alloy and y lies between 3,5 and 10.

In those alloys, ductile fibres were obtained by an appropriate choice of composition together with the fabrication method using directed or directional solidification.

In many cases the mixtures required for "TR" and "X" in order that the Co dentrites be present resulted in just sufficient magnetic properties, especially in rather low values of the coercive force, compared with those obtainable in a most straight forward system based on Co and Sm. For example an alloy having 15% (atomic) copper required Lanthanum in an amount of 30% of total TR (the balance being Sm) in order to ensure the formation of ductile dentrites. Such mixtures, which essentially modify the composition of the matrix can also have deleterious effects on the magnetic properties. It is the principal object of the present invention to improve the above mentioned alloys and method for fabricating high-performance magnets, especially of small dimensions and high precision, and also large magnets, which enables casting to be used and provides a product which can be subsequently machined without the difficulties encountered heretofore.

Another object of the invention is to provide magnets which are readily machined and yet retain the high magnetic-energy product B x H characteristic of rare-earth/cobalt magnets.

According to the invention, a metallic alloy for making ductile permanent magnet by directional solidification has a ductile phase composed essentially of Co in combination with chromium or iron plus chromium, which is dispersed in a magnetic matrix whose composition lies between $TR(Co,X)_5$ and $TR_2(Co,X)_{17}$, the alloy consisting essentially of TR, cobalt and X, where TR is at least one element selected from the group which consists of samarium, gadolinium praseodymium, cerium, neodymium, holmium, lanthanum and yttrium, X is at least one metal selected from the group comprising copper, iron, nickel, chromium, aluminium, molybdenum and manganese, TR is present in an amount of 10 to 15 at.% of the alloy, X is present in an amount of 10 to 40 at.% of the ally and cobalt is present in an amount of 50 to 80 at.% of the alloy. X includes iron and/or chromium in an amount of 0.1 to 10% (atomic) of the alloy with 0,1 to 5% (atomic) chromium in any event and most advantageously, chromium in an amount of 0,5 to 5% (atomic) of the alloy (inclusive).

The ternary composition is a composition represented by the shaded region A, B, C, D of Fig. 5.

The magnetic properties cited hereunder are the saturation magnetization ($M_s$) and the coercive force ($H_c$).

According to the invention we have now discovered that additions of chromium to such alloys in relatively small quantities have the surprising effect of provoking the formation of ductile dentrites without significantly affecting the magnetic properties of the matrix.

Iron, which also is included in component X also has a similar effect, but not so pronounced as Cr. Useful magnets can however be made especially well when the Cr additions are made to alloy compositions already containing a certain proportion of Fe. The reasons for the effectiveness of Cr as a dendrite former in these materials can be partially explained by the results obtained by microprobe analysis for the

compositions of the phases present: the Cr appears to be preferentially incorporated into the ductile dendrite phase, leaving relatively little in the matrix phases to interfere with their (magnetic) hardenability. The Fe is similarly distributed preferentially into the ductile dendrites, though the effect is less pronounced as can be seen in Table 1.

The quantities of Cr required depend on the proportions of the components TR and X relative to the Co content as can be seen from the examples in Table 2 together with an indication of the magnetic hardening which can be achieved.

The incorporation of the Cr into the dendrite phase in the form of a solid solution does not markedly affect the ductility of the phase, although the magnetic saturation can be substantially modified; Fe additions increasing the value, and Cr additions strongly reducing it. The dendrites do not seem to have a major effect on the magnetic properties of the bulk material. They do however have secondary effects by reducing squarences of the hysteresis loop. The reduction of $M_s$ of the dendrites due to the Cr is therefore an advantage as the loop squareness is less deformed.

Magnetic properties of the matrix phases are also affected by the addition of Cr but the effects are only small as relatively little Cr is incorporated into the matrix phases. The value of $M_s$ is slightly reduced, but most importantly there is very little effect on the hardenability ($H_c$) as compared with that obtained in the Sm-Co-Cu materials without the dendrites. At the Cr concentration levels required to form the dendrites, the reactions responsible for the magnetic hardening appear undisturbed.

A further consequence of the small quantities of Cr required to form the dendrites, and the coercive field obtained from such alloys, is that it is now much easier to make a useful magnet which is poor in the Tr component (i.e. the matrix phases of the $Tr(Co,X)_5$ and $TR_2(Co,X)_{17}$ type phase, which has less TR.

Use of such a matrix for the present magnets has two advantages — the amount of costly rare-earth in the alloy is minimized, and the properties are improved, since the $Sm_2Co_{17}$ type compounds have a significantly higher saturation magnetization that the $SmCo_5$ type compounds (12.8 kGs and 11.2 kGs respectively).

In principle the alloy composition could be adjusted such that no $TR(Co,X)_5$ compound is formed, the magnet then consisting only of ductule Co dendrites and the $TR_2(Co,X)_{17}$ phase. However we have found that a certain proportion of the $TR(Co,X)_5$ type phase is of considerable aid, and that the composition is advantageously adjusted such that approximately 5—30% of the magnet consists of this phase. (The proportion is for the finished material, after heat-treatment; before heat treatment the volume fraction of this phase is rather higher).

There are two advantages to maintaining the presence of the $TR(Co,X)_5$ type phase; firstly the production of the oriented structure formed by directional solidification is facilitated and secondly the presence of a small proportion of the $TR(Co,X)_5$ phase improves the hardenability (increase $H_c$) of the material.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

Fig. 1 is a schematic phase diagram illustrating a peritectic composition and serving for the purpose of explantion of a process according to the present invention;

Fig. 2 is a schematic phase diagram illustrating a eutectic composition enabling another form of the process to be explained;

Fig. 3 illustrates forms of the growth of the ductile and magnetic phases according to the phase diagram of fig. 1;

Fig. 4 is a diagram illustrating the cellular or dendrite growth which results when the process illustrated by fig. 2 is carried out;

Fig. 5 is a ternary diagram illustrating the composition ABCD which is an example of the alloys of the present invention;

Fig. 6 is a photomicrograph (50X enlargement) illustrating the composite structure of the material of the present invention;

Fig. 7 is a photomicrograph (6X) of a microstructure of an alloy according to the invention with ductile cobalt dendrites evidencing no cracking although it was subjected to solidification at a high cooling rate;

Fig. 8 is a photomicrograph of the alloy of fig. 7 (6X) without ductile cobalt dendrites showing the cracking resulting from cooling with the same regimen;

Fig. 9 is a graph showing the results of the three-point bending test of an alloy with ductile dendrites according to the invention;

Fig. 10 is a graph showing the corresponding results for an alloy without ductile dendrites; and

Fig. 11 is a hysteresis diagram illustrating a feature of the invention.

The ordinate in fig. 1 represents the temperature T while the abscissa shows the content in atomic percent of TR, the vertical lines 1, 2 and 3 indicating respectively the compositions within the ambit of the present invention. X may be one or more metals selected from the group which consists of iron, nickel, aluminium, chromium, copper, molybdenum and manganese. The alloy should contain 0.1 to 10% (atomic) iron and/or chromium with 0.1 to 5% (atomic) chromium present in any event. The most preferred composition contains 0.5% to 5% and more advantageously 1 to 5% chromium (atomic).

According to a preferred embodiment of the invention it is possible to obtain a composite

formed of a magnetic matrix $TR(Co,X)_y$ with y comprised between 5 and 8,5 together with a ductile phase (Co,X) in cellular or dendritic form. An alloy is solidified along the line y (Fig. 1). In this figure, T represents the temperature and is plotted along the ordinate while the TR content, in atomic percent is plotted along the abscissa. The lines 1, 2 and 3 represent the compound $TR_2(Co,X)_{17}$, $TR(Co,X)_5$ and $TR_2(Co,X)_7$.

Ductile dendrites 32 (fig. 3) are obtained in the magnetic matrix 31 from the system of fig. 1. The solidification front 33 separates the liquid phase 34 from the solid phase 35. The interfaces are shown at 36 and the distance between the dendritic fibers 37 is larger than in the previous case, e.g. about 50 microns. The fiber length may exceed 100 microns and the diameter of the fibers may be 25 to 30 microns on the average.

According to a second embodiment of the invention a molten alloy of the composition y (fig. 2) will cool along the arrow to give a eutectic mixture of the matrix of $TR_2(Co,X)_{17}$ and fibers or lamellae of another phase such as (Co,X). X, as noted, represents an element which can be substituted for cobalt such as iron, nickel, aluminium, copper, chromium, molybdenum and manganese for a mixture thereof such as iron and chromium with copper, or copper plus nickel, for example.

During the solidification, ductile fibers 11 (fig. 4) in a magnetic matrix 12 are obtained. The solidification front 13 separates the liquid phase 14 from the solidifying phase 15. At 16 are shown the various interfaces between the two phases. 17 represents the distance between the ductile fibers which can vary between 1 and 10 microns according to the speed of solidification. The fiber length is a multiple of a distance between the fibers and the fibers may extend continuously throughout the body or in length upward of 100 microns.

A brittle body can be made tougher according to the invention, by the introduction of a second ductile phase, with its associated interphase boundaries in the material. A composite body formed of two brittle phases is tougher than either of the phases taken alone and the mechanical properties of the composite body containing the two phases are improved. Even better properties can be obtained when one of the phases is a ductile phase which is associated with the brittle phase. The workability of the body is improved by the double effect of the presence of a ductile phase and the existence of phase interfaces.

The mechanical and particularly the magnetic properties of the alloy according to the invention can be improved by controlling the solidification to give an oriental structure as described. A directional-solidification furnace as described in U.S. patent 3,871,335 issued 13 March 1975 can be used to achieve this process. Such a directional-solidification furnace may include a crucible which is moved at a predetermined speed relative to the heating elements just allowing the solidification conditions, the liquidus/solidus interface temperature gradient, solidification speed and the like to be established as is necessary to ensure the growth of the fiber phase.

The orientation is primarily important for obtaining the optimum magnetic properties. Magnetic hardening in all cases is obtained by provoking precipitation as is conventional in the art. For example, the magnetic hardening can be carried out by subjecting the cast body to a solution treatment at a temperature above 900°C followed by precipitation by example at 400° to 700°C for one to two hours.

A similar improvement in the mechanical properties and magnetic properties of a body can be obtained by casting the alloy in a mold which is cooled at the base, thereby carrying out directed solidification. Using an alloy of the composition y of fig. 2, a structure similar to that in fig. 4 is obtained although the fibers may be partly or completely in cellular or dendritic form. Similarly with the alloys shown in fig. 1, e.g. of composition y, a structure similar to that shown in fig. 3, although the dendrites may have secondary branches, is formed.

The composition range in which magnetic alloys may be prepared according to the invention are represented by the shaded region A, B, C, D of fig. 5, the presence of the ductile dendrites depending on the detailed choice of the mixture for TR and X. In fig. 5, the cobalt content is plotted along the lower axis in atomic percent the TR content is plotted along the right hand axis in atomic percent and the replacement metal X is plotted along the left hand axis in atomic percent. The shaded region ABCD of the diagram represents compositions of magnetic alloys with between 10 and 40 at.% of the element X, where X is one or more of the elements iron, nickel, aluminium, copper, chromium, molybdenum and manganese. TR is present in an amount of 10 to 15 atomic percent of the alloy, X constitutes 10 to 40 atomic percent of the alloy and cobalt 50 to 80 atomic percent of the alloy.

Preferred composition ranges have TR consituted by Sm or Sm mixed with up to 40% of Pr or Ce. X is preferably a mixture of Cu, or Cu and Ni, together with Cr or Cr + Fe. Examples of such composi-tions are shown in tables 1 through 3.

The advantages of the magnets according to the present invention are numerous. They have high magnetic properties (BH max>10 MGOe, table 3) which are stable over long periods and under various environmental conditions. Their mechanical properties are superior to those of TR-cobalt magnets as are presently available, particularly with respect to their ability to be machined as proven by comparative tests. They can be machined by chip-removal methods, thereby allowing magnets of a wide range of shapes and sizes to be fabricated. They can be

readily ground and hence given precision dimensions. Their toughness in use if superior to commercial TR-cobalt magnets. Finally, it is possible to cast large pieces by the methods described above, since the improvement of the mechanical properties of the pieces allows them to be better able to resist the thermal stresses occurring on cooling.

From the foregoing it will be apparent that, while the alloy contains 10 to 15 at.% at TR, the ductile phase is composed essentially of cobalt and chromium or chromium + iron and the composition of the magnetic matrix is represented between $TR(Co,X)_5$ to $TR_2(Co,X)_{17}$.

Fig. 6 shows, in photomicrograph form the composite of the present invention in which the ductile cobalt dendrites can readily be distinguished from the brittle magnetic matrix. After a regimen of rapid cooling the composite of the invention (fig. 7) shows no evidence of cracking) composition corresponding to that of Example A I) while a similar composition (modified to avoid dendrites but reproduce the matrix composition) without the formation of the ductile dendrites (fig. 8) shows heavy cracking.

Figs. 9 and 10 give the test results for these two alloys, showing the remarkable improvement resulting from the presence of the cobalt ductile dendrites. All of the compositions given have good magnetic properties as well.

The test method was a three-point bend test effected on a notched square-section bar, in which the fracture surface is triangular as defined by the notches.

The method is well known and was developed by TATTERSALL and TAPPIN. Ref. J. Mat. Sci. 1 (1966) 296.

Fig. 9 is a test diagram on an alloy with ductile dendrites showing the charge (c) applied to the bar versus the displacement (d). The fracture energy for this sample was $\lambda_F = 247$ J./m².

Fig. 10 is a similar test diagram for an alloy without ductile dendrites. The fracture energy is only $\lambda_F = 5$ J./m².

In some magnetic bodies as described it has been noted that the magnetic behavior showed no signs of resulting from a "composite" body in that the hysteresis loops are essentially undeformed and reasonably square (see a fig. 11), despite the fact that the ductile dendrite phase is magnetically soft. These dendrites appear not to contribute to the overall behavior when they are grown "in situ". Once the material is ground finely the expected composite behavior is manifested.

Thus for an alloy of composition (by weight) 11% Sm, 15% Cu, 5% Fe, 2% Cr balance Co (~ 20% dendrites) the directionally solidified body has the same values for $4\pi M_s$ and Br of ~ 7.5 kGs. The same body reduced to powder has the same value for Br but the values for $4\pi M_s$ in the first quadrant of the hysteresis loop are increased to ~ 9.0 kGs and in the second (technically important) quadrant, reduced by a similar amount due to the effect of the dendrites (see b. fig 11)

TABLE 1
Results of Microprobe Analysis of Cr-Containing Magnets

| | Co | Sm | Cu | Atom. % Fe | Cr | Volume fraction% |
|---|---|---|---|---|---|---|
| ALLOY no 1 | 66.5 | 13.5 | 15.0 | — | 5.0 | |
| Dendrite Phase | 79.6 | 0.8 | 1.3 | — | 18.3 | ~ 10% |
| Matrix Phases 2:17 type | 74.1 | 11.8 | 8.3 | — | 6.1 | ~ 30% |
| Matrix Phases 1:5 type | 61.6 | 15.7 | 20.7 | — | 2.5 | ~ 60% |
| ALLOY no 2 | 64.0 | 12.5 | 12.5 | 8.0 | 3.0 | |
| Dendrite Phase | 73.7 | 0.7 | 1.7 | 14.5 | 9.3 | ~ 5% |
| Matrix Phases 2:17 type | 67.8 | 11.1 | 7.6 | 9.0 | 3.8 | ~ 45% |
| Matrix Phases 1:5 type | 58.7 | 14.6 | 18.2 | 7.8 | 2.1 | ~ 50% |
| ALLOY no 3 | 68.0 | 10.0Sm 2.5La | 12.5 | 4.0 | 3.0 | |
| Dendrite Phase | 80.0 | 0.8 | 1.9 | 7.7 | 9.6 | ~ 10% |
| Matrix Phases 2:17 type | 74.2 | 11.3 | 7.0 | 4.1 | 3.4 | ~ 35% |
| Matrix Phases 1:5 type | 62.7 | 14.9 | 18.1 | 2.6 | 1.7 | ~ 55% |

TABLE 2

| COMPOSITION | | | | | % DENDRITES (volume) | (HEAT TREATMENT NOT OPTIMIZED) Hc(KOe) |
|---|---|---|---|---|---|---|
| TR | | Cu | Fe | Cr | | |
| 13.5 | Sm | 15 | 0 | 5 | 20 | 3.2 |
| 13.5 | Sm | 15 | 0 | 4 | 5 | 4.7 |
| 12.5 | Sm | 15 | 0 | 3 | 10 | 4.5 |
| 12.5 | Sm | 12.5 | 0 | 4 | 5 | 4.1 |
| 11.0<br>2.5 | Sm<br>La | 15 | 0 | 5 | 20 | 3.2 |
| 11.0<br>2.5 | Sm<br>Pr | 15 | 0 | 5 | 20 | 3.8 |
| 10.0<br>2.5 | Sm<br>Pr | 12.5 | 4 | 3 | 25 | 3.9 |
| 10.0<br>2.5 | Sm<br>Ce | 12.5 | 4 | 3 | 20 | 5.3 |
| 12.5 | Sm | 12.5 | 4 | 3 | 5 | 4.8 |
| 11.3 | Sm | 13.7 | 4.3 | 2 | 12 | 4.5 |
| 11.4 | Sm | 13.7 | 4.3 | 2 | 10 | 6.5 |
| 11.4 | Sm | 13.7 | 8.3 | 2 | 15 | 6.3 |
| 11.3 | Sm | 13.7 | 6.3 | 2 | 15 | 5.8 |
| 11.3 | Sm | 13.7 | 6.3 | 1 | 5 | 4.1 |

EXAMPLES

| | COMPOSITION % AT. | | | | | STRUCTURE VOLUME % | | | MAGNETIC PROPERTIES | | | MECHANICAL PROPERTIES | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sm | Co | Cu | Fe | Cr | % ductile dendrites | % 2:17 | % 1:5 | Hc(KOe) | Ms(KGs) | BH max | fracture energy $Jm^{-2}$ | bend strength $MN^{-2}$ |
| A | 10 | 70 | 14 | 5 | 1 | 20 | 75 | 5 | 5.4 | 8.0 | 13 | 110 | 75 |
| B | 10 | 69.5 | 14 | 5 | 1.5 | 25 | 70 | 5 | 6.0 | 7.6 | 12 | 140 | 85 |
| C | 10.5 | 67.5 | 15 | 5 | 2 | 25 | 60 | 20 | 6.2 | 7.5 | 12 | 140 | 85 |
| D | 11 | 67 | 15 | 5 | 2 | 20 | 55 | 25 | 6.0 | 7.5 | 12 | 110 | 75 |
| E | 11.5 | 66.5 | 15 | 5 | 2 | 15 | 45 | 40 | 6.0 | 7.7 | 12.5 | 80 | 65 |
| F | 11 | 69 | 14 | 5 | 1 | 10 | 60 | 30 | 6.0 | 8.3 | 14.5 | 50 | 55 |
| G | 11 | 64 | 14 | 10 | 1 | 15 | 50 | 35 | 5.5 | 8.5 | 15.5 | 80 | 65 |
| H | 10.5 | 69.5 | 13 | 6 | 1 | 15 | 65 | 20 | 5.8 | 8.3 | 15 | 80 | 65 |



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**Claims**

1. A magnetic alloy for a ductile permanent magnet comprising a ductile phase of a cellular or dendritic structure composed essentially of Co in a magnetic matrix whose composition lies between $TR(Co,X)_5$ and $TR_2(Co,X)_{17}$ the alloy consisting essentially of TR, cobalt and X, where TR is at least one element selected from the group which consists of samarium, gadolinium, praseodymium, cerium, neodymim, holmium, lanthanum ad yttrium, X is at least one metal selected from the group which consists of copper, iron, nickel, aluminium, molybdenum and manganese, TR is present in an amount of 10 to 15 at.% of the alloy, X is present in an amount of 10 to 44 at.% of the alloy and cobalt is present in an amount of 50 to 80 at.% of the alloy, characterized in that X includes iron and/or chromium in an amount of 0.1 to 10% (atomic) of the alloy with 0.1 to 5% (atomic) chromium in any event.

2. The alloy defined in claim 1 characterized in that X contains 0.5 to 5 at.% chromium.

3. The alloy defined in claim 1 characterized in that TR is essentially samarium mixed with up to 50 at.% of the total TR of other rare-earth type elements.

4. The alloy defined in claim 1, characterized in that X is essentially Cu with up to 50 at.% of the total X.

5. A process for making a ductile magnetic alloy as defined in any one of claims 1 to 4 comprising the steps of:

— melting a mixture of essentially the elements Co, X, TR;

— cooling said melt by controlling the temperature gradient in the liquid, and the growth rate of the solid, such that after solidification the orientation of easy magnetization of most TR-Co grains are approximately parallel;

— controlling the temperature gradient in the liquid and the growth rate of the solid during the step of cooling so as to ensure the formation of a fine and uniform distribution of a ductile phase of cellular or dendritic structure within a magnetic matrix whose composition lies between $TR(Co,X)_5$ and $TR_2(Co,X)_{17}$; and

— heating the solid alloy in order to magnetically harden the TR-Co grains.

6. A body of magnetic alloy made by the process of claim 5 consisting of a ductile phase in a magnetic matrix, the ductile phase comprising Co, the magnetic matrix being of rare-earth-cobalt type, said body exhibiting an energy product of at least 6 M G Oe and a mechanical energy to rupture of at least 40 Joule/m².

7. The body of claim 6, characterized in that it exhibits an energy product of at least 10 M G Oe.

**Patentansprüche**

1. Magnetische Legierung für einen duktilen Permanentmagneten, umfassend eine duktile Phase aus einer zellularen oder dendritischen Struktur, die im wesentlichen aus Kobalt in einer magnetischen Matrix besteht, deren Zusammensetzung zwischen $TR(Co,X)_5$ und $TR_2(Co,X)_{17}$ liegt, wobei die Legierung im wesentlichen aus TR, Kobalt und X besteht, worin TR mindestens ein Element ist ausgewählt aus der Gruppe, die aus Samarium, Gadolinium, Praseodym, Cer, Neodym, Holmium, Lanthan und Yttrium besteht, X mindestens ein Metall ist, ausgewählt aus der Gruppe, die aus Kupfer, Eisen, Nickel und Aluminium, Molybdän und Mangan besteht, wobei TR in einer Menge von 10 bis 15 At.-Gew.-% der Legierung vorliegt, X in einer Menge von 10 bis 40 At.-Gew.-% und Kobalt in einer Menge von 50 bis 80 At.-Gew.-% der Legierung vorliegen, dadurch gekennzeichnet, daß X Eisen und/oder Chrom in einer Menge von 0,1 bis 10% (atomar) der Legierung umfaßt, mit in jedem Falle 0,1 bis 5% (atomar) Chrom.

2. Legierung nach Anspruch 1, dadurch gekennzeichnet, daß X 0,5 bis 5 At.-Gew.-% Chrom enthält.

3. Legierung nach Anspruch 1, dadurch gekennzeichnet, daß TR im wesentlichen Samarium gemischt mit bis zu 50 At.-Gew.-% des gesamten TR von anderen Elementen vom Typ seltener Erden ist.

4. Legierung nach Anspruch 1, dadurch gekennzeichnet, daß X im wesentlichen aus Kupfer ist mit bis zu 50 At.-Gew.-% des gesamten X.

5. Verfahren zum Herstellen einer duktilen magnetischen Legierung nach einem der Ansprüche 1 bis 4, gekennzeichnet durch die Schritte:

— Aufschmelzen eines Gemisches im wesentlichen der Elemente Co, X, TR;

— Abkühlen der Schmelze durch Steuern des Temperaturgradienten in der Flüssigphase und der Aufwachsrate des Solidus derart, daß nach der Verfestigung die Orientierung der leichten Magnetisierung der meisten TR-Co-Körner im wesentlichen parallel ist;

— Steuerung des Temperaturgradienten in der Flüssigphase und der Aufwachsrate des Solidus während des Abkühlschrittes derart, daß die Bildung einer feinen und gleichförmigen Verteilung einer duktilen Phase zellularer oder dendritischer Struktur innerhalb einer magnetischen Matrix sichergestellt wird, deren Zusammensetzung zwischen $TR(Co,X)_5$ und $TR_2(Co,X)_{17}$ liegt; und

— Erhitzen der verfestigten Legierung zwecks magnetischer Härtung der TR-Co-Körner.

6. Körper aus magnetischer Legierung, hergestellt durch das Verfahren nach Anspruch 5, bestehend aus einer duktilen Phase in einer magnetischen Matrix, wobei die duktile Phase Co umfaßt, die magnetische Matrix vom Typ seltene-Erde-Kobalt ist und der Körper ein Energieprodukt von mindestens 6 M G Oe und

eine mechanische Reißenergie von zumindest 40 Joule/m² aufweist.

7. Körper nach Anspruch 6, dadurch gekennzeichnet, daß er ein Energieprodukt von mindestens 10 M G Oe besitzt.

**Revendications**

1. Alliage magnétique pour aimant permanent ductile, comprenant une phase ductile, de structure cellulaire ou dendritique, composée essentiellement de Co dans une matrice magnétique dont la composition est comprise entre $TR(Co,X)_5$ et $TR_2(Co,X)_{17}$, l'alliage consistant essentiellement en TR, cobalt et X, où TR est au moins un élément choisi dans le groupe composé par le samarium, le gadolinium, le praséodyme, le cérium, le néodyme, l'holmium et l'yttrium, et X est au moins en métal choisi dans le groupe composé par le cuivre, le fer, le nickel, l'aluminium, le molybdène et le manganèse, TR étant présent en une quantité allant de 10 à 15% (atomique) de l'alliage, X étant présent en une quantité allant de 10 à 40% (atomique) de l'alliage et le cobalt étant présent en une quantité allant de 50 à 80% (atomique) de l'alliage, caractérisé en ce que X comprend du fer et/ou du chrome en une quantité allant de 0,1 à 10% (atomique) de l'alliage avec de 0,1 à 5% (atomique) de chrome dans tous les cas.

2. L'alliage selon la revendication 1, caractérisé en ce que X contient 0,5 a 5% (atomique) de chrome.

3. L'alliage selon la revendication 1, caractérisé en ce que TR est essentiellement du samarium mélangé avec jusqu'à 50% (atomique) du TR total d'autres éléments du type terres rares.

4. L'alliage selon la revendication 1, caractérisé en ce que X est essentiellement du cuivre avec jusqu'à 50% (atomique) du X total.

5. Procédé de production d'un alliage magnétique ductile selon l'une quelconque des revendications 1 à 4, suivant lequel:

— on fond un mélange composé essentiellement des éléments Co, X et TR;

— on refroidit la fusion en réglant le gradient de température du liquide et le taux de croissance du solide, de tell sorte que, après solidification, l'orientation de la magnétisation facile de la plupart des grains de TR-Co soit approximativement parallèle;

— on règle le gradient de température dans le liquide et le taux de croissance du solide pendant l'opération de refroidissement de manière à assurer la formation d'une distribution fine et uniforme d'une phase ductile de structure cellulaire on dendritique au sein d'une matrice dont la composition est comprise entre $TR(Co,X)_5$ et $TR_2(Co,X)_{17}$; et

— on chauffe l'alliage solide afin de durcir magnétiquement les grains de TR-Co.

6. Corps d'alliage magnétique préparé par le procédé de la revendication 5, composé d'une phase ductile dans une matrice magnétique, la phase ductile comprenant du Co, la matrice magnétique étant du type terres rares/cobalt, ledit corps présentant un produit d'énergie d'au moins 6 MGOe et une énergie mécanique à la rupture d'au moins 40 Joules/m².

7. Corps selon la revendication 6, caractérisé en ce qu'il présente un produit d'énergie d'au moins 10 MGOe.

Fig. 2

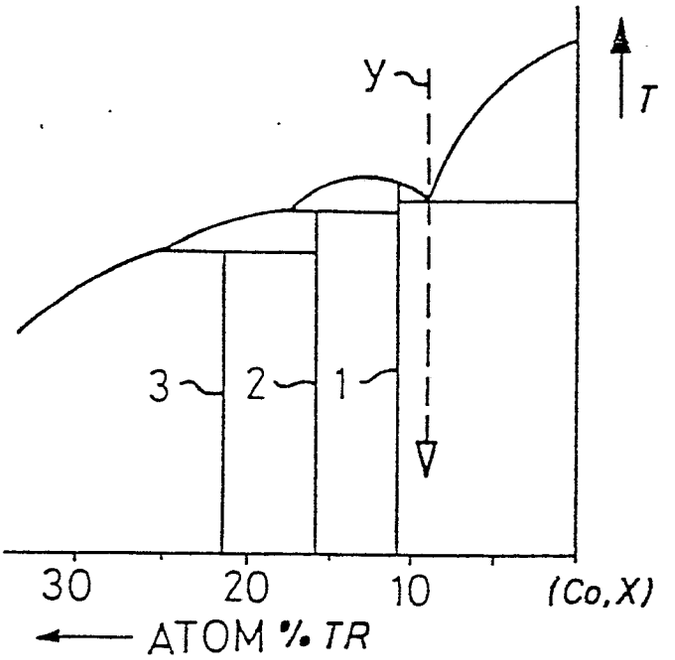



Fig. 1

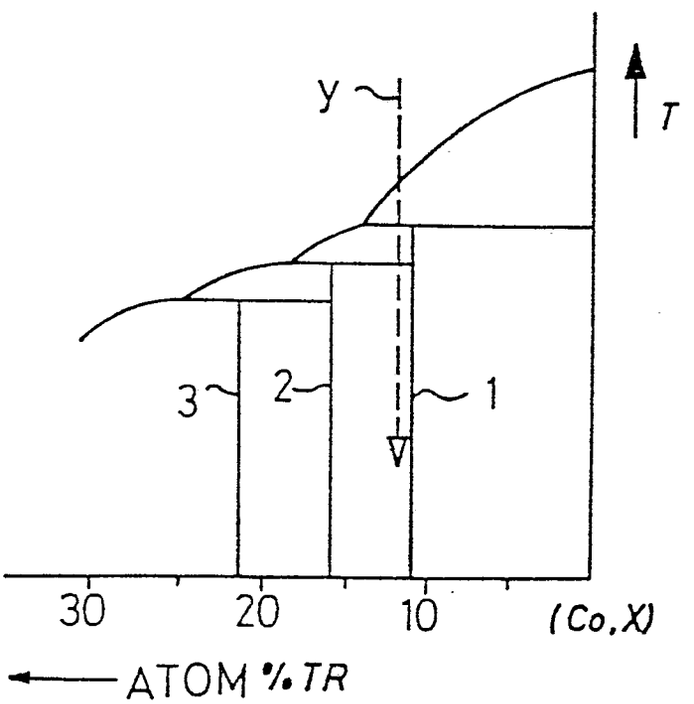


Fig. 4

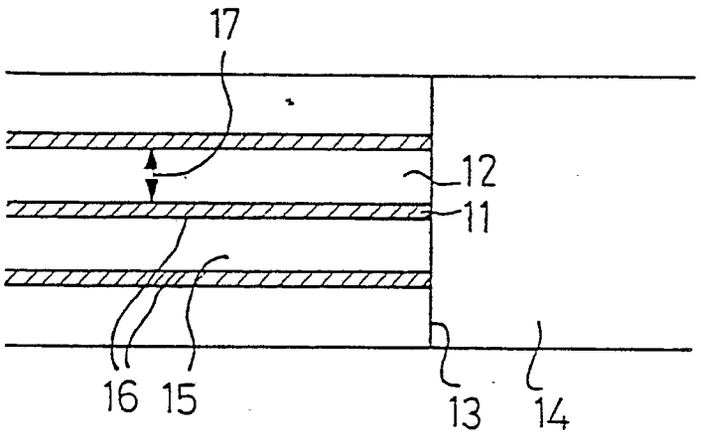



Fig. 3

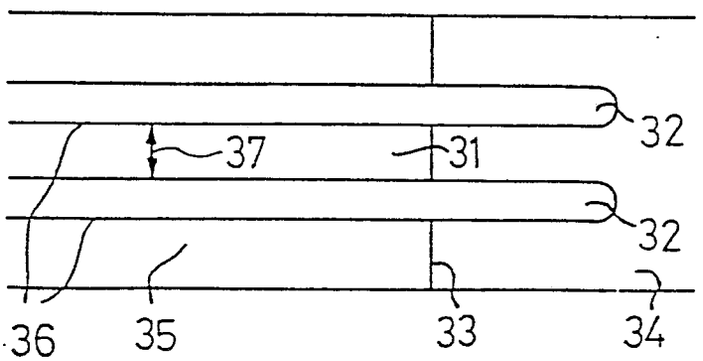
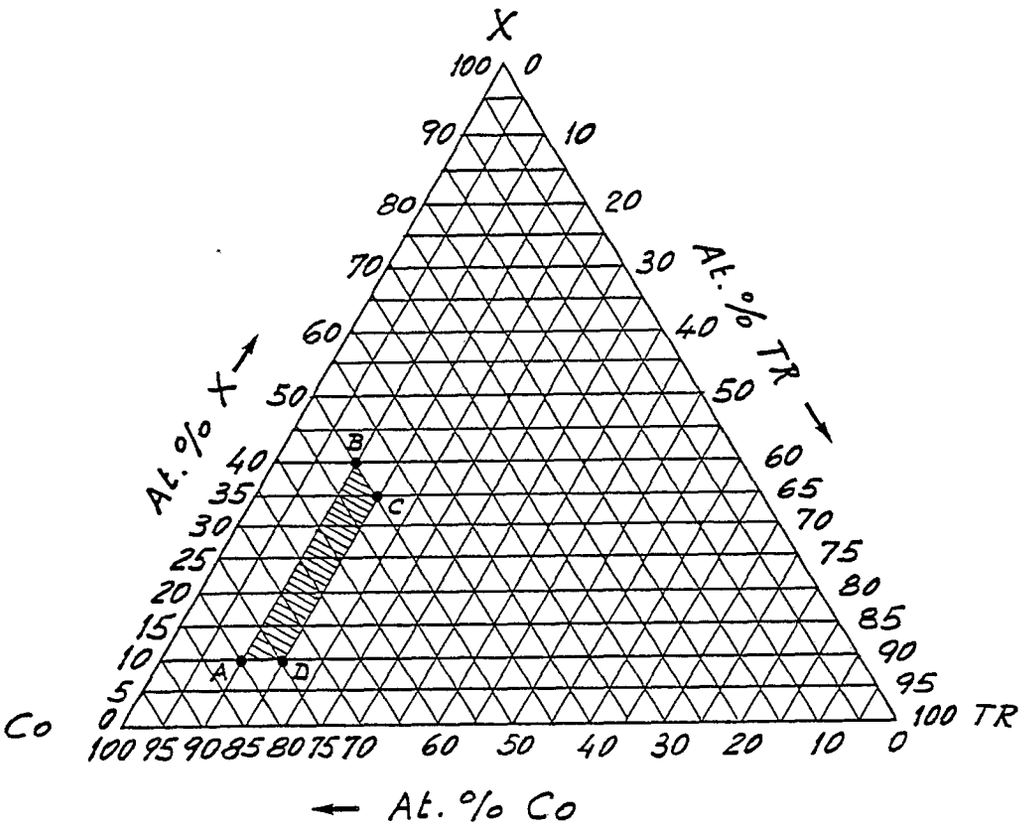


FIG.5


X
100 0
90 10
80 20
70 30
60 40
50 50
40 60
35 65
30 70
25 75
20 80
15 85
10 90
5 95
0 100 TR
At. % X
At. % TR
B
C
A
D
Co
100 95 90 85 80 75 70 60 50 40 30 20 10 0
At. % Co

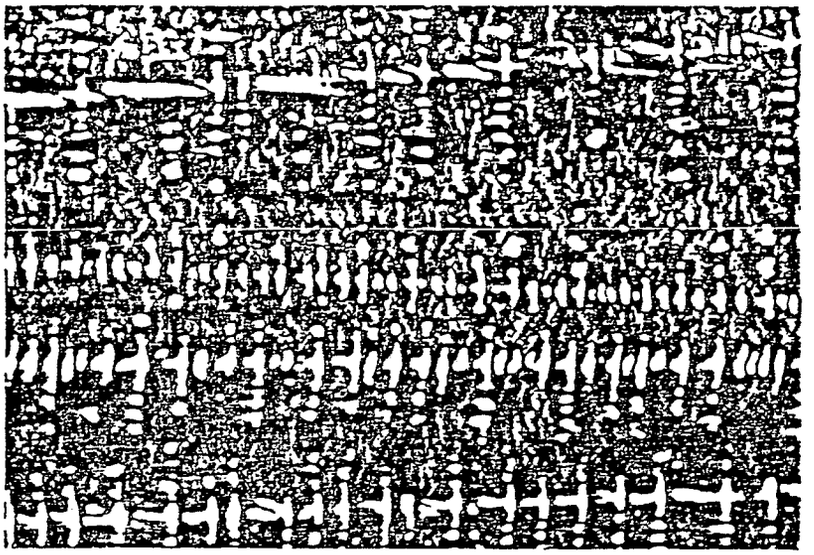


Fig. 6

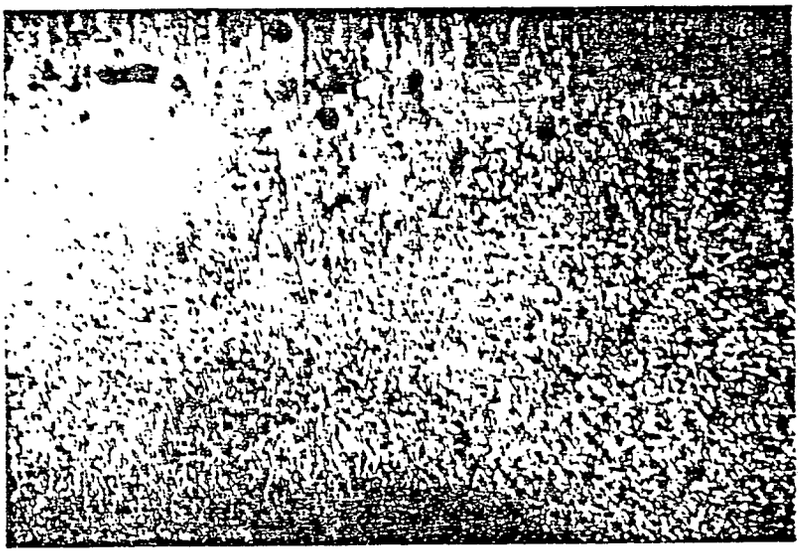
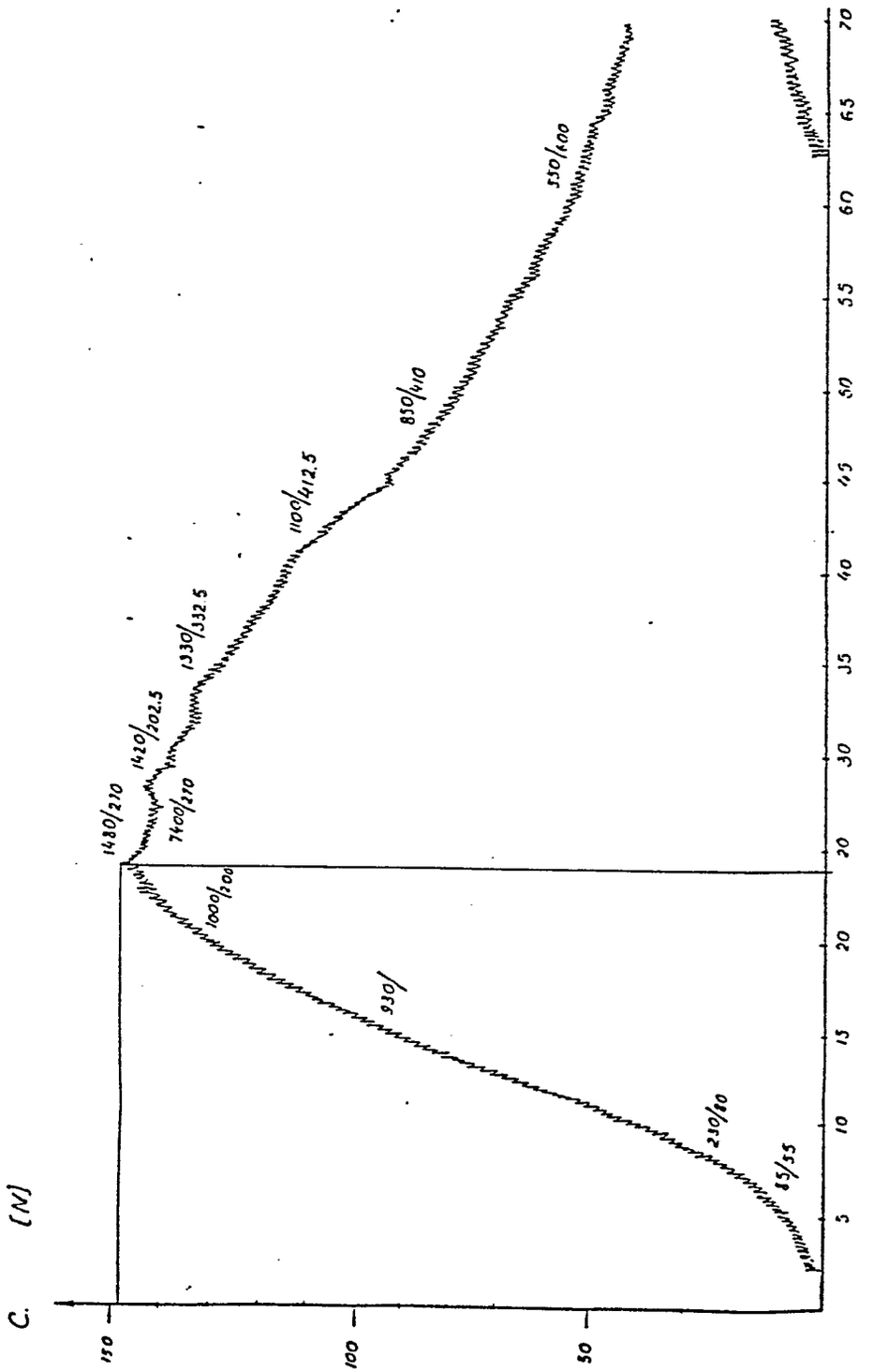


Fig. 7

Fig. 8


C. [N]
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100
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1420/302.5
7400/210
1330/332.5
1100/412.5
850/410
550/600
1000/500
930/
230/80
85/35
3
10
15
20
30
35
40
45
50
55
60
65
70
d. [µm]

Fig. 9

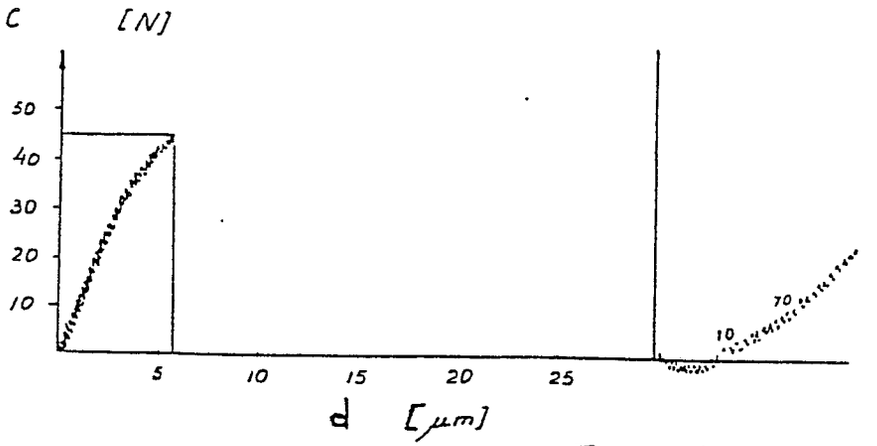


Fig. 10

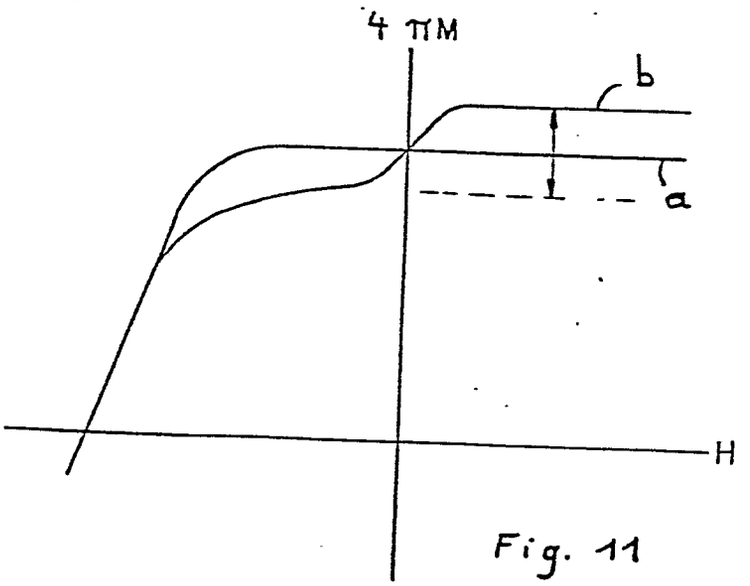


Fig. 11