(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 254 932 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: 21.10.92

(51) Int. Cl.5: C21D 6/00, H01F 1/16

(21) Application number: 87109970.1

(22) Date of filing: 10.07.87

(54) Heat treatment of rapidly quenched Fe-6.5 wt si ribbon.

(30) Priority: 01.08.86 US 894139

(43) Date of publication of application:
03.02.88 Bulletin 88/05

(45) Publication of the grant of the patent:
21.10.92 Bulletin 92/43

(84) Designated Contracting States:
DE FR GB

(56) References cited:
DE-A- 3 021 224

PATENT ABSTRACTS OF JAPAN, vol. 7, no. 97 (C-163)[1242], 23rd April 1983; & JP-A-58 22 331 (PIONEER K.K.) 09-02-1983

IEEE TRANSACTIONS ON MAGNETICS, vol. MAG-20, no. 4, July 1984, pages 553-558, IEEE, New York, US; C.F. CHANG et al.: "Texture and magnetic properties of rapidly quenched Fe-6.5wt%Si ribbon

(73) Proprietor: ALLIED-SIGNAL INC. (a Delaware corporation)
Columbia Road and Park Avenue P.O. Box 2245R
Morristown New Jersey 07960(US)

(72) Inventor: Das, Santosh Kumar
c/o Allied Corporation P.O. Box 2245R
Morristown, NJ 07960(US)
Inventor: Chang, Chin-Fong
c/o Allied Corporation P.O. Box 2245R
Morristown, NJ 07960(US)
Inventor: Bye, Richard Lister JR.
c/o Allied Corporation P.O. Box 2245R
Morristown, NJ 07960(US)

(74) Representative: Myerscough, Philip Boyd et al
J.A.Kemp & Co. 14, South Square Gray's Inn
London, WC1R 5EU(GB)

EP 0 254 932 B1

Rank Xerox (UK) Business Services

Description

This invention relates to a heat-treatment of rapidly quenched Fe-6 to 7, especially 6.5, wt% Si that, by controlling an order-disorder reaction, results in improved magnetic properties at high induction levels.

Fe-6.5 wt% Si alloy has extremely desirable ferromagnetic properties but has poor mechanical properties. It ordinarily has poor ductility and is not easily formed into thin ribbons or sheets that can be stamped or wound into selected shapes. US-A-4 649 983 teaches a method of processing Fe-Si alloys containing 6 to 7 wt% Si to produce thin, ductile ribbon with improved magnetic properties. To produce the ribbon, a stream of molten alloy is ejected through a nozzle and rapidly quenched on the circumferential surface of a rapidly rotating disk, thereby forming a continuous sheet of alloy. The as-cast ribbon is then vacuum annealed at temperatures ranging from 1000 °C to 1200 °C to obtain a columnar grain structure of a controlled size with a <100> fiber texture. This process results in a material with a power loss of 0.46 W/kg and an exciting power of 0.62 VA/kg at B = 1.0 T and f = 60 Hz, these properties being isotropic in the plane of the ribbon. No teaching is contained therein regarding induction levels above 1.0 T.

The order-disorder phenomenon and the resulting phase diagram of high silicon-iron alloys have been reported in the literature. It is known that the order-disorder reaction affects the magnetic properties of materials ranging from those that are structure sensitive to those that are intrinsic. It has been reported that in Fe-6.5 wt% Si, magnetostriction decreases with the growth of the DO3 domains and magnetic anisotropy decreases with the growth of the B2 domains. Through appropriate heat treatments to control the order-disorder reaction, material was produced with a maximum permeability ()m) of 52,000, and a coercive force (H_c) of 0.088 Oe at a maximum induction of 1.0 T. These properties are not useful for electromagnetic applications such as transformers, generators, and motors, however. In these devices, properties such as low ac core loss and exciting power at high induction levels (greater than 1.0 T) are essential. No attempt has been made to improve the magnetic properties of rapidly quenched Fe-6.5 wt% Si at high induction levels by controlling the order-disorder reaction.

The invention provides a method of heat treatment for rapidly quenched Fe-Si alloys containing 6 to 7 wt% Si which promotes an order-disorder reaction, thereby improving the magnetic properties at high induction levels, comprising the steps of:

vacuum annealing at a temperature between 1000 °C and 1200 °C for 1 to 4 hours to develop <100> texture with intensity at least 2 times random and a grain size of 1-2 mm; and

annealing at a temperature of 500 °C to 900 °C for 1 to 4 hours and cooling at a rate sufficient to retain the annealed domain structure comprised of 100 to 850 nm B2 domains and 5 to 25 nm DO3 domains.

In addition, the invention provides an improved crystalline ribbon of an Fe-Si metal alloy containing 6 to 7 weight percent Si said ribbon having transverse dimensions much less than its length, of an Fe-Si alloy containing 6 to 7 wt% Si, said ribbon having:

a substantially <100> texture with intensity at least 2 times random;

a grain size of 1-2 mm;

a B2 domain size of 100 to 850 nm;

a DO3 domain size of 5 to 25 nm;

an ac core loss of 1.2 to 1.6 W/kg at an induction level of B = 1.4 T and at a frequency of f = 60 Hz; and

an exciting power of 15 to 46 VA/kg at an induction level of B = 1.4 T and at a frequency of f = 60 Hz. The ribbon is ductile enough so that it can be readily stamped, wound or otherwise formed into desired shapes. It has substantially isotropic ferromagnetic properties. These improved magnetic properties make the ribbon especially well suited for use in rotors and stators of electromagnetic devices such as motors and generators which operate at induction levels higher than 1.0 T.

Referring to the drawings:-

Fig. 1 shows dark field transmission electron micrographs of B2 (1a) and DO3 (1b) ordered domain structures using superlattice reflections corresponding to the B3 and DO3 structures in selected area diffraction in a ribbon annealed at 1100 °C for 1 hour in vacuum, and annealed at 825 °C for 1 hour in hydrogen atmosphere,

Fig. 2 shows representative micrographs of the grain size and grain morphology of a Fe-6.5 wt% Si ribbon annealed at 1100 °C for 1 hour; and

Fig. 3 shows a (200) pole figure of a Fe-6.5 wt% Si ribbon annealed at 1100 °C for 1 hour.

For purposes of the present invention and as used in this specification, a ribbon is a slender body whose transverse dimensions are much less than its length. Such ribbon may be in the form of a ribbon, strip, or sheet, that is narrow or wide and of regular or irregular cross-section. Also for the purposes of the present invention, a ribbon is considered to be ductile if it can be bent around a radius of 10 times its thickness without fracture.

It is well known that single crystals of iron have a cubic crystalline structure and are most easily magnetized in the <100>, less easily magnetized in the <110> direction, and least easily magnetized in the <111> direction. These directions are expressed in standard crystallographic rotation. This magnetic anisotropy has a strong effect on static hysteresis losses during alternating magnetization. In cores for rotating machines the magnetic field is in the plane of the sheet, but the angle between the field and the longitudinal direction of the sheet varies as the core rotates. It is therefore desirable to have a material with a texture such that the "hard" (most difficult to magnetize) <111> direction is not in the plane of the sheet. A <100> "fiber" texture (i.e. a texture in which all grains have a <100> direction normal to the sheet surface and in all possible rotational positions about this normal) is most desirable in ferromagnetic materials in rotating equipment because the sheet then has isotropic ferromagnetic properties in its own plane. A material is considered to have substantially isotropic ferromagnetic properties when its ferromagnetic properties, as determined by the B-H curve thereof, do not vary by more than 20% when measured in any direction within the plane of the ribbon.

The term "texture" as used herein, means the predominate orientation of the crystal grains within the metal when compared to a reference sample having randomly oriented grain crystals. Texture can be determined by conventional techniques, such as X-ray diffraction and electron diffraction analysis.

The present invention provides a method of processing as-cast ribbons of Fe-Si alloys containing 6 to 7 wt% Si to obtain optimum B2 and DO3 domain structures. Ribbon processed by the method of this invention is ductile and has improved magnetic properties such as power loss and exciting power at high induction levels. Generally stated, the ribbon is rapidly solidified and then processed by a two-step annealing process. In step (ii) the required cooling rates are readily achieved by furnace cooling in a hydrogen atmosphere.

In rapidly solidified Fe-Si alloys containing 6 to 7 wt% Si that have been subjected to the first step anneal only, the B2 domain size is approximately 160 nm and there is no evidence of DO3 domains. Ac core losses and exciting power in these materials, while attractive at induction levels below about 1.0 T, increase rapidly at higher induction levels. After the second annealing step of this invention, both B2 and DO3 domains are present and ac core losses and exciting power are substantially improved at induction levels above approximately 1.2 T.

A typical example of the B2 and DO3 domain structure in a Fe-6.5 wt% Si alloy subjected to the heat treatment of this invention is shown in Figure 1. The domain size is strongly dependent on annealing temperature and only weakly dependent on annealing time. Annealing at temperatures in the lower range of this invention (500 ° C to 700 ° C) results in a large domain size in the ribbon. A smaller domain size can be achieved by annealing at the higher temperatures of this invention (700 ° C to 900 ° C). In general, higher second step annealing temperatures and longer annealing times result in smaller B2 and DO3 domain sizes and in lower ac core losses and exciting power at high induction levels. Preferably, the second annealing step is carried out at a temperature between 790 ° C and 860 ° C. Fe-Si ribbon annealed by this preferred procedure has a B2 domain size of 100-250 nm, a DO3 domain size of 5 to 10 nm, an ac core loss of 1.2 to 1.5 w/kg and an exciting power of 15 to 26 VA/kg, the ac core loss and exciting power being measured at an induction level of 1.4 T and a frequency of 60 Hz.

The retained ductility and improved magnetic properties of rapidly solidified Fe-Si alloys containing 6 to 7 wt% Si results from the refinement of the ordered domain size thereof. Advantageously, such alloys, when subjected to the two step annealing process of this invention, are rendered especially suitable for use in rotating electromagnetic devices that operate at induction levels above about 1.2 T.

The following examples are presented in order to provide a more complete understanding of the invention.

Example 1

A strip of Fe-6.5 wt% Si alloy was cast using the planar flow casting process described in US-A-4,331,739. The as-cast strip had a 100% columnar grain structure with an average grain size of 2.3 x 10^{-5} m, and there were substantially no second phase particles at the grain boundaries. The strip had a near random texture. The material was annealed at 1100 ° C for 1 hour in vacuum to obtain the desired <100> texture and optimum grain size. Figure 2 shows representative micrographs of the grain size and grain morphology in a ribbon annealed at 1100 ° C for 1 hour. This annealed ribbon exhibits a strong <100> texture with intensity as high as 44 times random, as shown in Figure 3.

The domain structure was observed in a Transmission Electron Microscope (TEM) dark field of the superlattice reflections corresponding to the B2 and DO3 structures. The size of B2 domains in the ribbon annealed at 1100 ° C for 1 hour is about 160 nm. No evidence of DO3 domains was found in this ribbon.

The magnetic properties (ac core loss and exciting power) of this annealed ribbon are shown in Table 1. These measurements were made by winding the samples, after heat treatment, with 100 turn primary and secondary windings. Core loss measurements were made with a Dranetz 3100 sampling network analyzer. Primary current was determined from the voltage across a 0.1 ohm noninductive resistor in the primary circuit. Resistive losses in the primary circuit were excluded by measuring the induced secondary voltage. The network analyzer sampled these voltage waveforms and calculated the total loss. Exciting power was calculated from rms voltmeter measurements on the same voltage waveforms. A Hewlett Packard 9836 computer was utilized to control the network analyzer and frequency generator as well as to log data from them and from rms and average responding voltmeters via an IEEE 488 bus. A computer program allowed the induction, as calculated from the average responding voltmeter, to be automatically set at preselected values and then all readings logged. The computer calculated values for core loss and exciting power per kilogram. Voltage feedback from the secondary windings was necessary to maintain sinusoidal flux excitation due to the large exciting currents at high induction levels. Air-core flux compensators were also used due to these high exciting currents.

Table 1

ac core loss and exciting power of rapidly solidified Fe-6.5 wt% Si ribbon annealed at 1100°C for 1 hour, values measured at f=60 Hz.

Induction Level B_{Max} (T)	Core Loss W_t (W/kg)	Exciting Power P_z (VA/kg)
0.6	0.29	0.50
0.7	0.37	0.64
0.8	0.46	0.93
0.9	0.57	0.94
1.0	0.70	1.22
1.1	0.85	1.64
1.2	1.06	4.24
1.3	1.30	16.94
1.4	1.57	55.10

Examples 2-10

Samples of materials that had been cast and annealed as in Example 1 were given an additional annealing treatment at temperatures ranging from 500 ° C to 900 ° C for times ranging from 1 hour to 4 hours in a hydrogen atmosphere. After annealing, the furnace power was turned off and the sample allowed to cool to room temperature. Samples were prepared for microstructural analysis by TEM and for magnetic property measurement as described under Example 1. The following examples illustrate the effect of heat treatment on the domain size and magnetic properties of Fe-6.5 wt% Si ribbon.

The B2 and DO3 domain size, as determined from the TEM analysis, is listed in Table 2 for the different annealing temperatures and times.

Table 2

Effect of heat treatment on B2 and DO3 domain size of Fe-6.5 wt% Si after annealing at 1100° C for 1 hour.

Example	Annealing Temperature (°C)	Annealing Time (hours)	B2 domain Size (nm)	DO3 domain Size (nm)
2	500	1	840	21
3	600	1	550	20
4	700	1	480	14
5	800	1	110	7
6	800	2	210	7
7	800	4	230	7
8	850	1	220	7
9	850	2	210	7
10	850	4	190	7

Examples 2-10 illustrate that the order-disorder reaction in Fe-6.5 wt% Si, as reflected by the change of B2 and DO3 domain size, is strongly affected by the secondary annealing temperature, and relatively independent of annealing time.

The ac core loss and exciting power at various induction levels for these examples, measured at 60 Hz, is listed in Tables 3-8. No data is presented for Examples 7 and 8 due to unavailability of material from which to construct test specimens.

Table 3

Effect of heat treatment on ac core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100° C for 1 hour, measured at an induction level B=0.6 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	0.34	0.52
3	600	1	0.30	0.50
4	700	1	0.31	0.49
5	800	1	0.32	0.53
6	800	2	0.27	0.48
9	850	2	0.22	0.47
10	850	4	0.28	0.49

Table 4

Effect of heat treatment on ac core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100° C for 1 hour, measured at an induction level B=0.8 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	0.49	0.66
3	600	1	0.44	0.69
4	700	1	0.44	0.64
5	800	1	0.42	0.70
6	800	2	0.38	0.68
9	850	2	0.40	0.72
10	850	4	0.42	0.89

Table 5

Effect of heat treatment on ac core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100° C for 1 hour, measured at an induction level B=1.0 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	0.69	1.11
3	600	1	0.70	1.18
4	700	1	0.63	1.13
5	800	1	0.60	1.14
6	800	2	0.56	1.04
9	850	2	0.62	1.05
10	850	4	0.60	1.10

Table 6

Effect of heat treatment on AC core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100° C for 1 hour, measured at an induction level B=1.2 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	1.04	3.16
3	600	1	1.05	3.22
4	700	1	0.94	2.76
5	800	1	0.98	2.90
6	800	2	0.87	2.04
9	850	2	0.90	1.69
10	850	4	0.92	2.67

Table 7

Effect of heat treatment on ac core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100°C for 1 hour, measured at an induction level B=1.3 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	1.29	11.76
3	600	1	1.28	12.05
4	700	1	1.17	10.08
5	800	1	1.21	11.09
6	800	2	1.06	6.16
9	850	2	1.06	3.42
10	850	4	1.15	12.26

Table 8

Effect of heat treatment on ac core loss and exciting power of Fe-6.5 wt% Si after annealing at 1100°C for 1 hour, measured at an induction level B=1.4 T, frequency f=60 Hz.

Example	Annealing Temperature (°C)	Annealing Time (Hours)	Core Loss (W/kg)	Exciting Power (VA/kg)
2	500	1	1.60	42.92
3	600	1	1.63	41.89
4	700	1	1.41	39.86
5	800	1	1.50	45.82
6	800	2	1.32	25.54
9	850	2	1.26	15.36
10	850	4	1.40	38.72

The above examples clearly illustrate that rapidly solidified Fe-Si alloys containing 6 to 7 wt% Si and preferably 6.5 wt% Si have improved ac core loss and exciting power at high induction levels when processed by the method of this invention as compared to those having had a single-step anneal only. The improvement in core loss and exciting power is due to the refining of the domain structure as indicated in Table 2. Domain size refinement and, consequently, magnetic properties are particularly enhanced when the second anneal step of this invention is performed at temperatures within the preferred range, 800 ° C to 900 ° C.

Claims

1. A method of heat treatment for rapidly quenched Fe-Si alloys containing 6 to 7 wt% Si which promotes an order-disorder reaction, thereby improving the magnetic properties at high induction levels, comprising the steps of:
   vacuum annealing at a temperature between 1000 ° C and 1200 ° C for 1 to 4 hours to develop a <100> texture with intensity at least 2 times random and a grain size of 1-2 mm; and
   annealing at a temperature of 500 ° C to 900 ° C for 1 to 4 hours and cooling at a rate sufficient to retain the annealed domain structure comprised of 100 to 850 nm B2 domains and 5 to 25 nm DO3 domains.

2. A method according to claim 1, wherein said vacuum annealing step is performed at a temperature between 1075 ° C and 1125 ° C.

3. A method according to claim 2, wherein said second annealing step is performed at a temperature between 790 ° C and 860 ° C.

4. A method according to claim 1, 2 or 3, wherein said second annealing step is performed in a hydrogen atmosphere.

5. A method according to any one of claims 1 to 4, wherein said cooling after said second annealing step is performed in a hydrogen atmosphere.

6. A method according to any one of claims 1 to 5 wherein said cooling after said second annealing step is performed at a rate of between 15 and 35 ° C per minute.

7. A ribbon, that is a slender body having transverse dimensions much less than its length, of an Fe-Si alloy containing 6 to 7 wt% Si, said ribbon having:
   a substantially <100> texture with intensity at least 2 times random;
   a grain size of 1-2 mm;
   a B2 domain size of 100 to 850 nm;
   a DO3 domain size of 5 to 25 nm;
   an ac core loss of 1.2 to 1.6 W/kg at an induction level of B = 1.4 T and at a frequency of f = 60 Hz; and
   an exciting power of 15 to 46 VA/kg at an induction level of B = 1.4 T and at a frequency of f = 60 Hz.

8. A ribbon according to claim 7 wherein said B2 domain size is 100 to 250 nm.

9. A ribbon according to claim 7 or 8 wherein said DO3 domain size is 5 to 20 nm.

10. A ribbon according to claim 7, 8 or 9 wherein said ac core loss is 1.2 to 1.50 W/kg at an induction level of B = 1.4 T and at a frequency of f = 60 Hz.

Patentansprüche

1. Verfahren des Wärmebehandelns von rasch abgeschreckten Fe-Si Legierungen, welche 6 bis 7 Gewichts% Si enthalten, das eine Ordnungs/Unordnungs-Reaktion fördert und dadurch die magnetischen Eigenschaften bei hohen Induktionswerten verbessert, das folgende Schritte umfasst:
   Vakuum Ausglühung bei einer Temperatur zwischen 1000 ° C und 1200 ° C während 1 bis 4 Stunden, um eine <100> Textur mit einer zumindest zweifachen Zufallsintensität und einer Korngrösse von 1-2 mm; und
   Ausglühung bei einer Temperatur von 500 ° C bis 900 ° C während 1 bis 4 Stunden und Abkühlung mit einer Rate die ausreicht um die ausgeglühte Domänen-Struktur im Bereich von 100 bis 850 nm B2 Domäne und 5 bis 25 nm DO3 Domäne zu bewahren.

2. Verfahren gemäss Anspruch 1, wobei der besagte Vakuum Ausglühungsschritt bei einer Temperatur zwischen 1075 ° C und 1125 ° C ausgeführt wird.

3. Verfahren gemäss Anspruch 2, wobei der besagte zweite Ausglühungsschritt bei einer Temperatur zwischen 790 ° C und 860 ° C ausgeführt wird.

4. Verfahren gemäss Ansprüchen 1, 2 oder 3, wobei der besagte zweite Ausglühungsschritt in einer Wasserstoff-Atmosphäre ausgeführt wird.

5. Verfahren gemäss irgendeinem der Ansprüche 1 bis 4, wobei die besagte Abkühlung nach dem besagten zweiten Ausglühungsschritt in einer Wasserstoff-Atmosphäre ausgeführt wird.

6. Verfahren gemäss irgendeinem der Ansprüche 1 bis 5, wobei die besagte Abkühlung nach dem besagten zweiten Ausglühungsschritt bei einer Rate von zwischen 15 und 35 ° C pro Minute erfolgt.

7. Band, mit schlankem Körper und Querdimensionen, die viel weniger als dessen Länge ausmachen, aus einer Fe-Si Legierung, welche 6 bis 7 Gewichts% Si enthält, wobei das besagte Band:
im wesentlichen eine <100> Textur mit zumindest zweifacher Zufallsintensität,
eine Korngrösse von 1-2 mm,
eine B2 Domänengrösse von 100 bis 850 nm,
eine DO3 Domänengrösse von 5 bis 25 nm,
einen Wechselstrom-Kernverlust von 1.2 bis 1.6 W/Kg bei einem Induktionswert von B = 1.4 T und einer Frequenz von f = 60 Hz, und
eine Anregungsenergie von 15 bis 46 VA/Kg bei einem Induktionswert von B = 1.4 T und einer Frequenz von f = 60 Hz, aufweist.

8. Band gemäss Anspruch 7, in welchem die besagte B2 Domänengrösse 100 bis 250 nm beträgt.

9. Band gemäss Ansprüchen 7 oder 8, dessen besagter Wechselstrom-Kernverlust 1.2 bis 1.50 W/Kg, bei einem Induktionswert von B = 1.4 T und einer Frequenz von f = 60 Hz beträgt.

10. Band gemäss Anspruch 7, 8 oder 9, dessen besagter Wechselstrom-Kernverlust bei einem Induktionswert von B = 1.4 T und bei einer Frequenz von f = 60 Hz 1.2 bis 1.50 W/Kg beträgt.

Revendications

1. Procédé de traitement thermique pour des alliages de Fe-Si rapidement refroidis contenant 6 à 7 % en poids de Si qui encourage une réaction d'orientation-désorientation, améliorant de ce fait les propriétés magnétiques à des niveaux d'induction élevés, comprenant les étapes consistant à :
recuire sous vide à une température située entre 1000 ° C et 1200 ° C pendant 1 à 4 heures afin de développer une texture <100> avec une intensité d'au moins 2 fois au hasard et une dimension de grain de 1 à 2 mm, et
recuire à une température de 500 ° C à 900 ° C pendant 1 à 4 heures et refroidir à une vitesse suffisante pour maintenir la structure des domaines recuits constituée des domaines B2 de 100 à 850 nm et des domaines DO3 de 5 à 25 nm.

2. Procédé selon la revendication 1, dans lequel l'étape de recuit sous vide est effectuée à une température située entre 1075 ° C et 1125 ° C.

3. Procédé selon la revendication 2, dans lequel la seconde étape de recuit est effectuée à une température située entre 790 ° C et 860 ° C.

4. Procédé selon la revendication 1, 2 ou 3, dans lequel la seconde étape de recuit est effectuée dans une atmosphère d'hydrogène.

5. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel le refroidissement après la seconde étape de recuit est effectué dans une atmosphère d'hydrogène.

6. Procédé selon l'une quelconque des revendications 1 à 5, dans lequel le refroidissement après la seconde étape de recuit est effectué à une vitesse de refroidissement située entre 15 et 35 ° C par minute.

7. Ruban, qui est un corps mince ayant des dimensions transversales beaucoup moins importantes que sa longueur, d'un alliage de Fe-Si contenant 6 à 7 % en poids de Si, le ruban comportant :

une texture pratiquement <100> avec une intensité d'au moins 2 fois au hasard ;

une dimension de grains de 1 à 2 mm ;

une dimension des domaines B2 de 100 à 850 nm ;

une dimension des domaines DO3 de 5 à 25 nm ;

une perte de l'induit en courant alternatif de 1,2 à 1,6 W/kg à un niveau d'induction de B = 1,4 T et à une fréquence de f = 60 Hz, et

une puissance d'excitation de 15 à 46 VA/kg à un niveau d'induction de B = 1,4 T et à une fréquence de f = 60 Hz.

8. Ruban selon la revendication 7, dans lequel la dimension des domaines B2 est de 100 à 250 nm.

9. Ruban selon la revendication 7 ou 8 dans lequel la dimension des domaines DO3 est de 5 à 20 nm.

10. Ruban selon la revendication 7, 8 ou 9, dans lequel la perte de l'induit en courant alternatif est de 1,2 à 1,50 W/kg à un niveau d'induction de B = 1,4 T et à une fréquence de f = 60 Hz.

FIG. 1 a

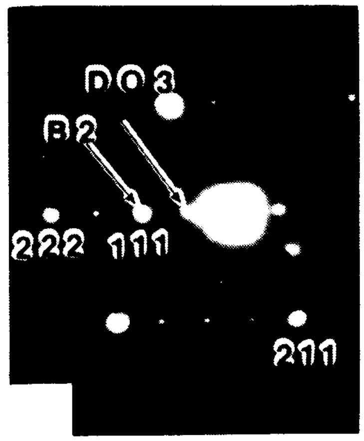

FIG. 1 b

FIG. 1 c

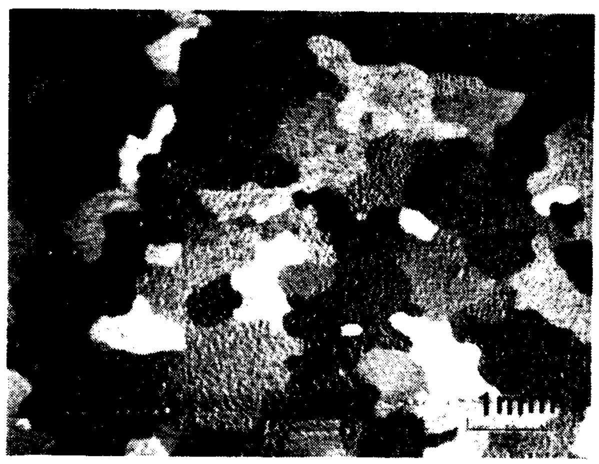

Fig. 2

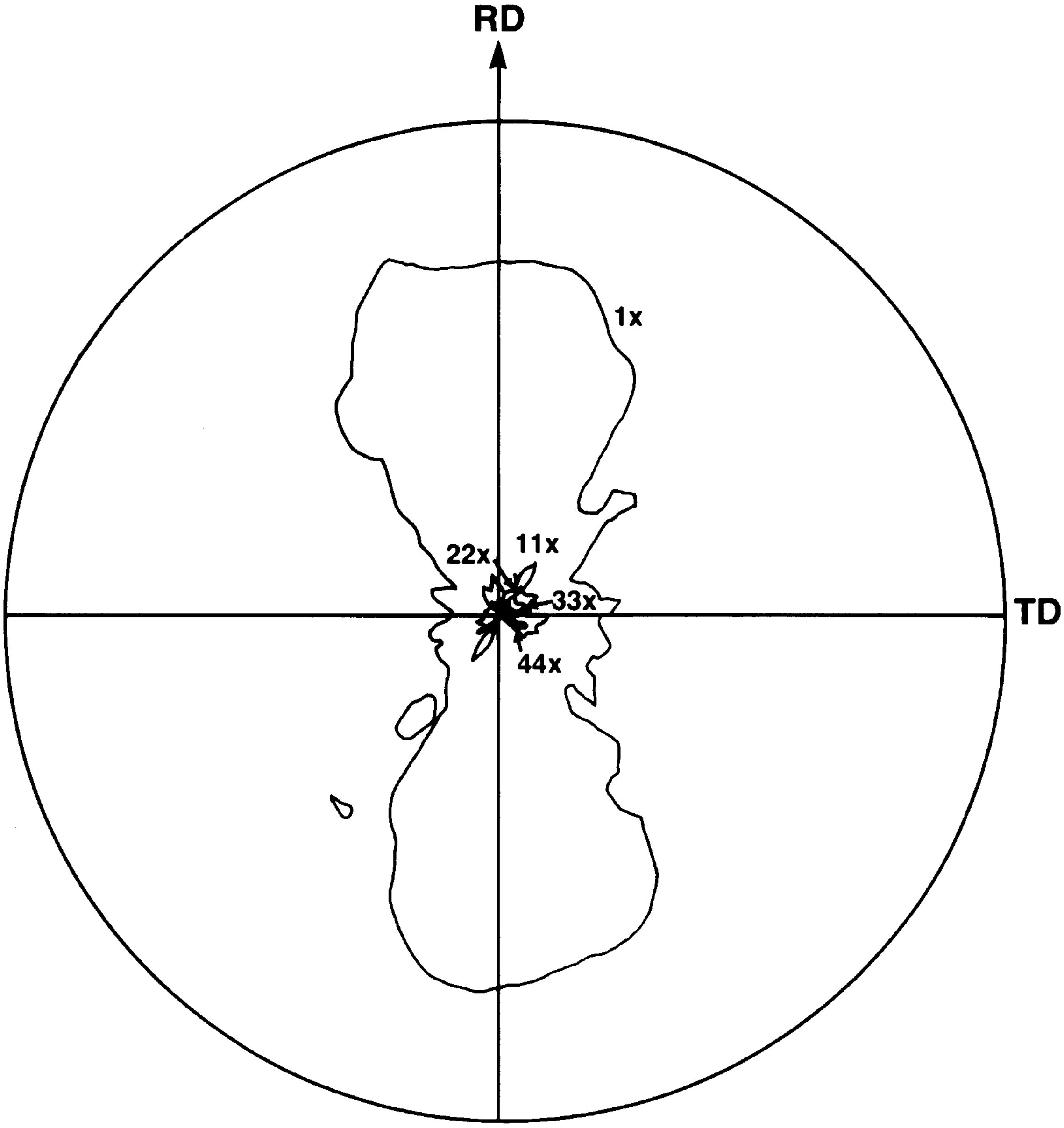

Fig. 3