Nov. 24, 1964 J. L. WALTER ETAL 3,158,516

METHOD FOR PRODUCING ALLOY BODIES HAVING IMPROVED MAGNETIC PROPERTIES

Original Filed June 26, 1961 2 Sheets-Sheet 1

Fig. 1.

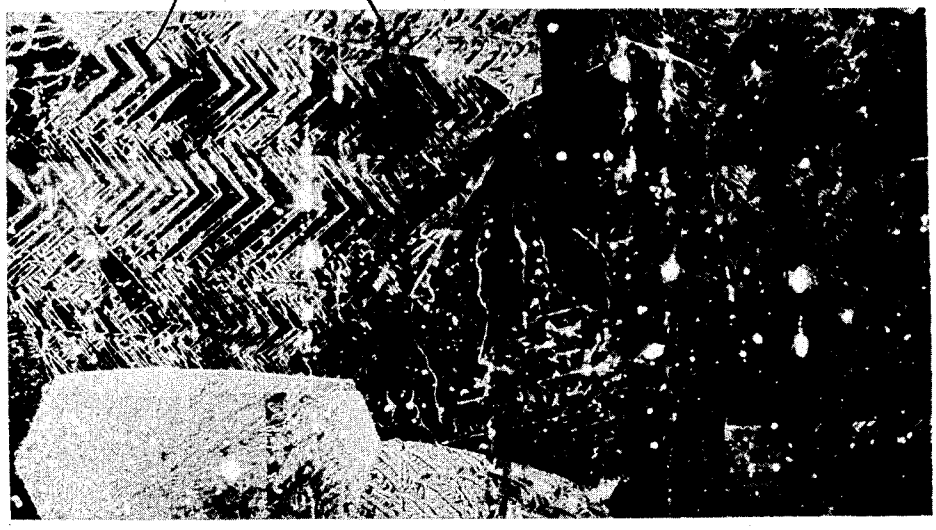
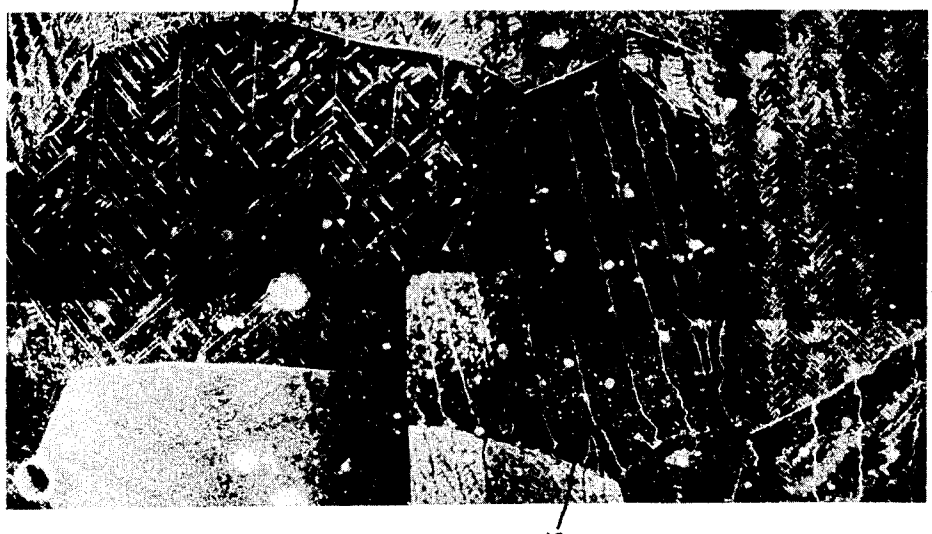


Fig. 2.



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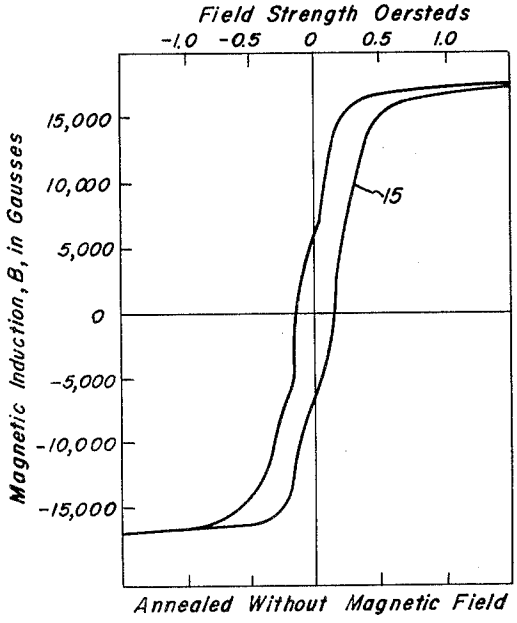


Fig. 3.

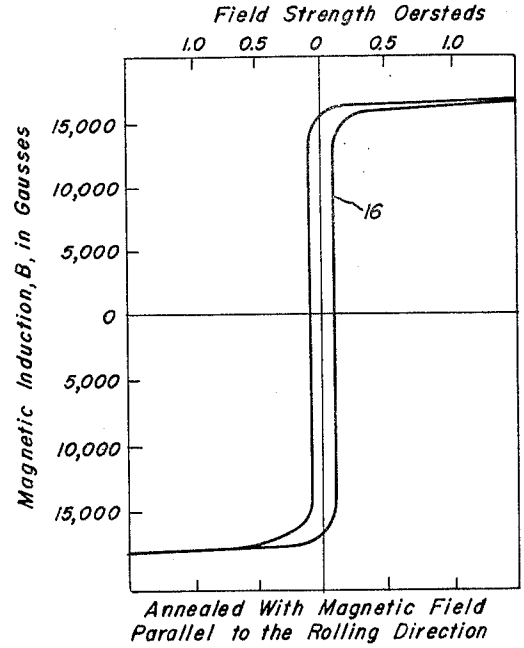


Fig. 4.

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3,158,516

METHOD FOR PRODUCING ALLOY BODIES HAVING IMPROVED MAGNETIC PROPERTIES

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Continuation of application Ser. No. 119,555, June 26, 1961. This application May 11, 1964, Ser. No. 366,530

2 Claims. (Cl. 148—108)

This invention relates to bodies composed of magnetic alloys and more particularly to a method for producing sheet-like bodies composed principally of iron and having improved magnetic and magnetostrictive properties.

This application is a continuation of applicants' copending application Serial No. 119,555, filed June 26, 1961, and assigned to the same assignee.

Iron-base alloys consisting of at least 92 percent iron and containing alloying agents such as silicon, aluminum, molybdenum, or some combination thereof, have found extensive use in electrical applications. For example, iron containing from 2 to 5 weight percent silicon, iron containing up to 8 weight percent aluminum, and iron containing up to 8 weight percent of combinations of silicon and aluminum have been widely used as transformer core materials.

The electrical and magnetic properties of the present alloys have been improved by aligning the unit cubes so that one or more easiest directions of magnetization exist. The invention is specifically concerned with sheet-like bodies composed of iron-base alloys having a body-centered cubic crystal structure in which a majority of the constituent grains are aligned in the (100) [001] orientation to produce two easiest directions of magnetization in the plane of the sheet. This orientation is generally referred to as "cube texture" and is typified by having a majority of the unit cubes so oriented that two cube faces are generally parallel to the rolling surface of the sheet-like body, two other faces are perpendicular to the rolling surface and generally parallel to the rolling direction and the remaining two unit cube faces are perpendicular to the rolling direction and to the rolling surface. A more complete discussion of the cube-texture grain orientation and of a method for producing the orientation in a sheet-like body is found in the copending application, Serial No. 610,909, of Hibbard et al., filed September 20, 1956, and assigned to the same assignee as the present invention.

It is a principal object of this invention to provide a method for improving the magnetic properties and reducing the magnetostriction of cube-textured sheet-like bodies composed of iron-base body-centered cubic alloys.

Other objects and advantages will be in part obvious and in part explained by reference to the accompanying specification and drawings.

In the drawings:

FIG. 1 shows the distribution of the magnetic domains within a silicon-iron body having cube texture;

FIG. 2 shows the distribution of the magnetic domains of the silicon-iron body of FIG. 1 following magnetic annealing;

FIG. 3 is a hysteresis loop illustrating the magnetic properties of a cube texture silicon-iron body annealed without a magnetic field and measured parallel to the rolling direction; and

FIG. 4 is a hysteresis loop of a cube texture silicon-iron body annealed in a magnetic field parallel to the rolling direction and measured parallel to the rolling direction.

Generally, this invention concerns sheet-like bodies composed of iron-base body-centered cubic alloys having cube texture orientation, which alloys have improved magnetic properties including lower magnetostrictive characteristics, and to a method for producing such bodies.

More specifically, the alloys used are iron-base alloys containing 2 to 5 percent silicon, up to 8 percent aluminum, up to 8 percent molybdenum and iron base alloys containing some combination of the three listed alloying additives. Other materials, such as carbon, oxygen and nitrogen are normally present in trace percentages, normally less than 0.02 percent, 0.006 percent and 0.001 percent, respectively. These alloys are suitably rolled into sheet-like bodies having the (100) [001] orientation so that two easiest direction of magnetization are in the plane, or rolling surface of the body. Bodies having at least 65 percent of the constituent grains oriented in the (100) [001] crystalline orientation are preferred although lower percentage orientations can be used in some instances.

Generally, the improved magnetic properties are obtained by taking appropriately-sized sheet-like bodies of the general compositions previously mentioned and heating them to an elevated temperature while subjecting them to a magnetic field of predetermined magnitude and direction. The bodies are then cooled from the elevated temperature at a rate of about 100° C. an hour in a dry hydrogen atmosphere while the magnetic field is maintained. The magnetic field causes an orientation or ordering of the magnetic domains within the material, which alignment is generally parallel to the direction in which the magnetic flux is directed. The magnetic field can be made to either align the magnetic domains parallel the longitudinal or rolling direction of the metal body or can be directed at right angles thereto. Approximately the same results are obtained from the magnetic and magnetostrictive standpoints, due to the fact that the cube-texture orientation provides two easiest directions of magnetization. The magnetostrictive values fall within the range of from about —0.5 to 1.0 microinch per inch and preferably within the range of from about —0.1 to 1.0 microinch per inch.

Referring to FIGS. 1 and 2 of the drawings, the effect on the magnetic domains of annealing in a magnetic field can be seen quite clearly. Referring to FIG. 1 first, lines 10 indicate the boundaries of magnetic domains, and it is apparent that the lines exhibit no substantial degree of common alignment. Since the boundaries are not aligned, it follows that the magnetic domains are similarly non-aligned and that optimum magnetic properties cannot be obtained.

Since the only difference between the body of FIGS. 1 and 2 is the fact that the body is magnetically annealed in FIG. 2, the effect of the magnetic anneal is evident. In FIG. 2, the lines 10 are generally parallel the rolling direction, this being the direction in which the magnetic field was directed.

To illustrate the effect of magnetic annealing on the magnetic properties of the bodies, reference is made to FIGS. 3 and 4. Specifically, the loop 15 of FIG. 3 shows the characteristics of the material when it is annealed without being subjected to a magnetic field. The residual magnetism (B_r) is relatively low and the entire curve is somewhat sheared, so that while the material can be used in electrical applications such as transformers, it does not represent a material having optimum characteristics. On the other hand, the hysteresis loop 16 of FIG. 4 is markedly different in that it has been "squared" so that the residual magnetism (B_r) is at a maximum.

Material having the properties indicated by loop 16 would be more useful in transformer applications than one having the properties evidenced by loop 15. The difference in the properties of the materials was brought

about by magnetically annealing the material to align the majority of the magnetic domains in generally the same direction, the direction in the present instance being parallel to the rolling direction of the sheet-like body.

Results obtained from magnetic annealing with alignment of the domains are illustrated by the following. A body of cube-texture silicon-iron was prepared and tested and annealed, first without a magnetic field, and subsequently in the presence of an applied magnetic field to align the magnetic domains. The watt losses, in watts per pound, and magnetostriction, in microinches per inch, of the sample before and after magnetic annealing were then measured parallel to the rolling direction with the body subjected to a field of about 15,000 gausses. The body annealed without the magnetic field had a watt loss of 0.67 watt per pound and a magnetostriction of 3.9 microinches per inch, whereas the magnetically annealed body had a watt loss of 0.58 watt per pound and magnetostriction of only 0.4 microinch per inch.

As a further example illustrating the effect of the magnetic anneal, an iron-base alloy having about 3 percent silicon and other incidental impurities such as oxygen, nitrogen and carbon, and having a majority of the constituent grains oriented in the (100) [001] direction, was heated to about 800° C. at a rate of about 100° per hour. The body was held at this temperature for about one hour and simultaneously subjected to a magnetic field of about 50 oersteds, the field being applied parallel to the rolling direction. Following annealing, the body remained subjected to the magnetic field and cooled at the rate of 100° C. an hour in dry hydrogen. The maximum permeability (μ_m) increased an average of 13 percent and the residual reduction (B_r) increased by 11 percent.

Additional sample bodies, about 12 mils thick and containing about 3 percent silicon, balance substantially all iron, were cut in the cross-grain direction and annealed in the manner just described, with the exception that the magnetic field was directed at right angles to the rolling direction. Average increases of 27 percent and 29 percent in residual induction and maximum permeability, respectively, were obtained when measured at right angles to the rolling direction, i.e., in the direction of the field. The test results are fully set forth in the following Table I:

Table I

	Before Magnetic Anneal	After Magnetic Anneal
H_c	0.14	0.11 oersted.
B_r	7,100	11,600 gausses.
B_2 oersteds	15,200	15,400 gausses.
μ_m	30,900	77,800.

Alloys other than iron-silicon may be similarly improved. For example, a 12 mil sheet-like body of an alloy of iron and containing 4 percent aluminum and normal percentages of non-metallic impurities, and having a majority of the constituent grains in the (100) [001] orientation, had the following properties before and after magnetic annealing. Each body was annealed in the longitudinal or rolling direction and the measurements were taken parallel to that direction.

Table II

	Before Magnetic Anneal	After Magnetic Anneal
H_c	0.20	0.20 oersted.
B_r	6,100	7,900 gausses.
B_2 oersteds	11,600	12,150 gausses.
μ_m	14,650	21,150.

Thus, from a review of the values set forth in Tables I and II, it is apparent that the magnetic annealing procedure results in material improvement in the magnetic properties of the bodies in both the longitudinal and cross directions. Of course, the improvements in a given body occur only in the direction in which the field is applied, a slight decrease in magnetic properties occurring in the other direction.

The magnetostriction of sheet-like bodies of suitable composition for use as core materials is, as already mentioned, an important factor to be considered. Magnetostriction is a change in the physical dimensions of a piece of metal resulting from passage of magnetic energy therethrough. In the case of core parts subjected to magnetic fields, this change in dimensions results in vibration, causing objectionable noise or hum. The vibration may also cause unnecessary wear, decreasing transformer performance and usable life. It is particularly important in a cube-textured alloy since the magnetostriction may be quite high in the rolling direction. One of the important features of this invention is the provision of a cube-textured iron-base alloy having low magnetostriction.

To illustrate the effect of magnetic annealing, two samples were prepared from 12 mil sheet material composed essentially of 3 percent silicon and the balance substantially all iron. These bodies were measured prior to and following a magnetic anneal. The magnetic field is parallel to the rolling direction so that the magnetic domains would align in the same direction. The samples were measured in a magnetic field of 15.5 kilogausses and the magnetostriction measured. The results are shown in Table III:

Table III

Sample:	Magnetostriction (microinches/inch)
1 (annealed)	5.0
2 (annealed)	3.9
1 (mag. annealed)	0.5
2 (mag. annealed)	0.4

Thus, the present invention provides an improved method for producing bodies of cube-textured iron-base alloys which have improved magnetostriction characteristics as well as improved magnetic properties.

Although the present invention has been described in connection with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A method for improving the magnetic characteristics of a sheet-like body composed of body-centered cubic magnetic material consisting essentially of at least 92 percent iron, up to 5 percent silicon, up to 5 percent molybdenum, and up to 8 percent aluminum having an initial magnetostriction greater than zero and having a majority of the constituent grains thereof in the (100) [001] orientation to provide two directions of easiest magnetization in the plane of said sheet-like body, said method comprising heating said sheet-like body to an elevated temperature at about the Curie point and cooling said body while simultaneously subjecting it to an applied magnetic field acting substantially parallel to one of the easiest directions of magnetizations to align the magnetic domains and cause the body to have a magnetostriction of from about −0.5 to 1.0 when subjected to a magnetic field of about 15.5 kilogausses applied generally parallel to one of the easy directions of magnetization.

2. A method for improving the magnetic characteristics of a sheet-like body composed of body-centered cubic magnetic material consisting essentially of at least 92 percent iron, up to 5 percent silicon, up to 5 percent molyb-

denum, and up to 8 percent aluminum having an initial magnetostriction greater than zero and having a majority of the constituent grains thereof in the (100) [001] orientation to provide two directions of easiest magnetization in the plane of said sheet-like body, comprising heating said sheet-like body to an elevated temperature at about the Curie point, and cooling said body at a rate not in excess of 100° C. per hour until a temperature of about 200° C. is reached, and simultaneously subjecting the body to a magnetic field while

cooling is occurring, the magnetic field acting substantially parallel one of the easiest directions of magnetization to align the magnetic domains and cause the body to have a magnetostriction of from about −0.5 to 1.0 when subjected to a magnetic field of about 15.5 kilogausses applied generally parallel to one of the easy directions of magnetization.

No references cited.

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