

Jan. 29, 1963

F. W. DANIELS
MAGNETIC CORE MATERIAL

3,076,160

Filed Jan. 11, 1960

2 Sheets-Sheet 1

Fig. 1.

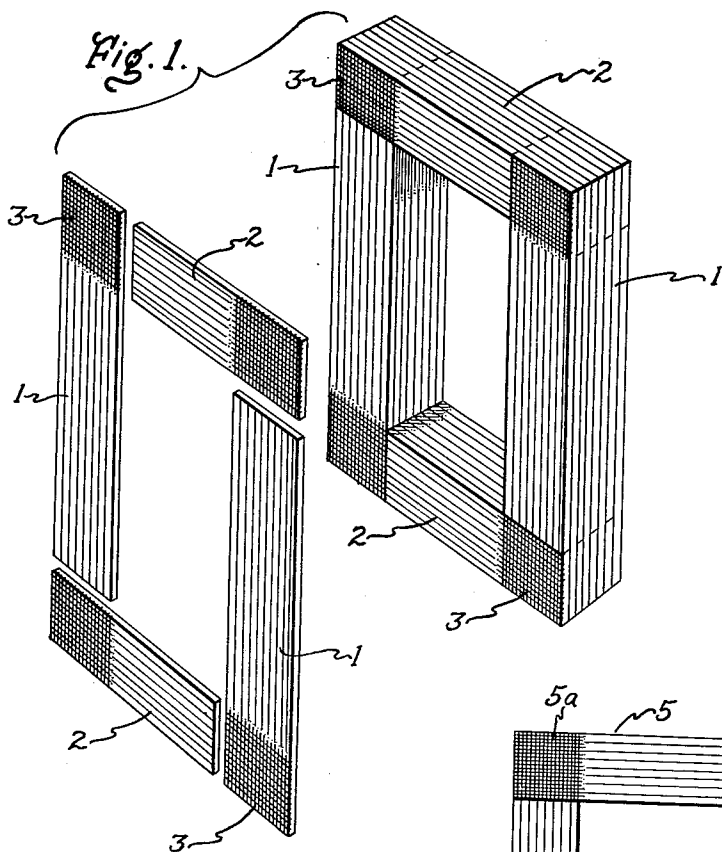


Fig. 2.

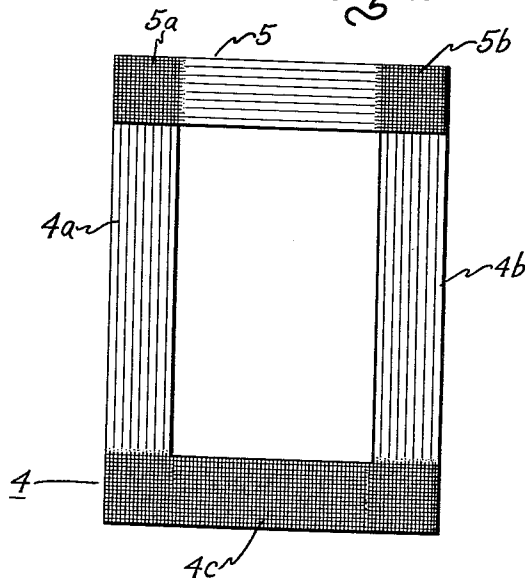
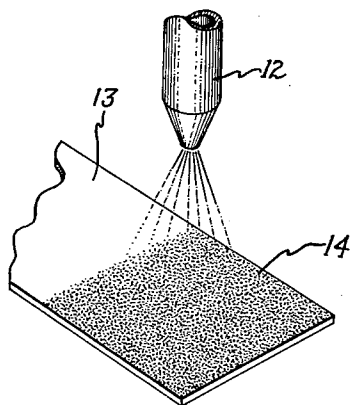


Fig. 6.



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Fig. 3.

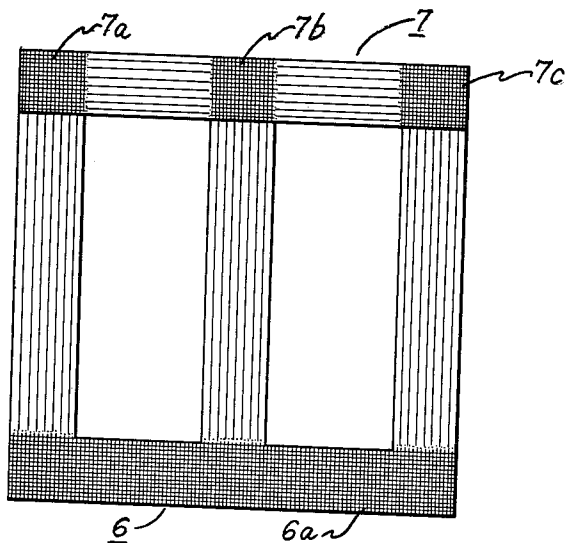


Fig. 5.

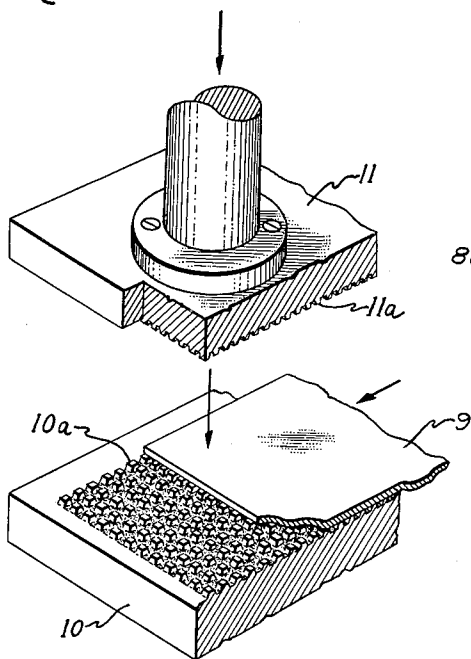
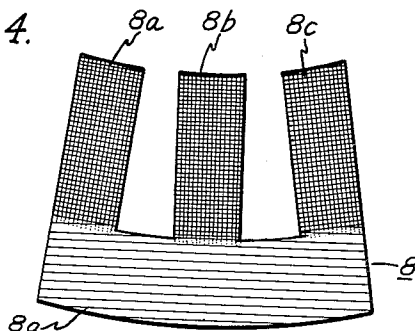


Fig. 4.



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3,076,160

MAGNETIC CORE MATERIAL

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3 Claims. (Cl. 336-218)

The present invention relates to magnetic core material for electrical induction apparatus, and more particularly to the treatment of such material for improving its electrical and magnetic characteristics.

In the usual construction of magnetic cores for use in electrical induction apparatus such as transformers, the cores are formed of stacked laminations of a suitable magnetic material such as silicon steel alloy, the laminations being cut or punched from relatively large sheets produced by rolling from bars or billets of the magnetic material.

High quality magnetic steel strip which is presently used in the industry for making the above-described magnetic core laminations has what is referred to as texture or grain orientation, a condition in which the axes of the crystals composing the strip are not randomly disposed in space but are aligned for the most part in a specific direction. It is known in the art that it is desirable to provide electrical sheet steel with a high degree of texture, i.e., preferred grain orientation, in order to obtain improved magnetic properties in the steel sheet and thereby increase the efficiency of electrical apparatus in which it is used.

Various metallurgical processes have been carried out in the past for obtaining a desired orientation of the crystals comprising the magnetic strip, and it has been the practice in general to process the steel strip by particular rolling and heating treatments to achieve the desired degree of grain orientation. For example, it is known that as a result of unidirectional rolling in the above process, the grain structure becomes oriented in the direction of rolling and that the magnetic flux path in the intended use of these strips should be parallel to this direction to obtain optimum results in the magnetic core operation.

To obtain the optimum crystallographic, magnetic, and electrical properties in the core steel to make it suitable for use in present day high voltage transformers, it is important to couple such unidirectional rolling procedures with proper annealing and purifying heat treatments, such as are already known and are more particularly described hereinafter for producing a high degree of magnetic anisotropy. Such heat treatments are employed, for example, to promote secondary grain growth to a high degree of crystal orientation in the finally processed steel strip. By secondary grain growth or secondary recrystallization is meant the process whereby in the final texture-producing annealing treatment, certain strain-free grains having the desired orientation grow in size at the expense of less favorably oriented grains. Such secondary grain growth follows primary recrystallization, which is defined as a process whereby the distorted grain structure of a cold-worked metal is replaced by a new strain-free grain structure by annealing above a specific minimum temperature. It is such secondary recrystallization that produces the highly preferred orientation sought in

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high quality magnetic strip and the orientation thus obtained is completely different from that obtained merely after primary recrystallization.

A difficulty encountered in the use of core laminations having such highly directional grain orientation is that at the corners and elsewhere in the lamination the magnetic flux path changes direction so that it is no longer parallel with the grain direction, and electrical losses and other adverse effects occur at their regions. Various steps have been taken and suggested in the past for avoiding or alleviating this condition. For example, the parts of the core lamination have been segmented and arranged to provide for closer correspondence between the direction of grain orientation and the flux path. In other cases, a continuous ribbon of magnetic steel has been wound in a coil. Other expedients have included the provision of mitered joints at the corners of the core lamination, with the ends butting or overlapping. More recently, the development of doubly oriented magnetic steel has offered a means for improving the magnetic properties at the corner regions of the core, since the double crystal orientation furnishes a highly permeable flux path in the material in directions at 90° to one another.

However, various drawbacks are attendant on the use of the above and other previously attempted solutions to the problem, such as the high cost of material or inconvenient assembly procedures involved in the various expedients suggested.

It is an object of the invention to provide for improved electrical and other properties of magnetic core material, especially in those regions thereof where the flux path is intended to travel in directions other than that of the preferred grain orientation of the core material.

It is still another object of the invention to provide the above results in magnetic core laminations by a simple, economical and convenient process which avoids the disadvantages of the procedures previously suggested in the prior art.

It is a specific object of the invention to provide for improved flux travel in the corners and other regions of magnetic core laminations by a simple procedure which may be incorporated in the usual process of treating magnetic material for the development of a high degree of grain orientation therein.

Other objects and advantages will become apparent from the following description and appended claims.

To attain the above objects, the present invention provides magnetic core sheet material having magnetic flux paths therein which are located at angles to one another, the sheet material in the region of one flux path being highly grain oriented in a direction parallel to one of the flux paths and being relatively randomly grain oriented in the region of another flux path disposed at an angle to the previously mentioned flux path. To achieve such core material, the invention provides in the process of treating the magnetic sheet material for producing therein a high degree of grain orientation, the step of treating selected portions of the magnetic material, wherein the magnetic flux is adapted to travel transverse the direction of the grain orientation, in a manner to impair the development of a high degree of grain orientation by the usual final annealing treatment subsequently employed in such processing of magnetic sheet material.

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The invention will be better understood from the following description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a view of a magnetic core formed of straight laminations to which the invention is applicable;

FIGURE 2 is a perspective view of a U-shaped core arrangement showing the application of the invention thereto;

FIGURE 3 is a view of an E-shaped magnetic core arrangement wherein the invention is applicable;

FIGURE 4 is a view of a segmental portion of a generator stator core showing the application of the present invention;

FIGURE 5 is a perspective fragmentary view of a device which may be used in practicing the present invention; and

FIGURE 6 shows another means for practicing the invention.

Referring now to the drawings, and particularly to FIG. 1, there is shown a magnetic core comprising legs made up of stacks of straight laminations 1, and yokes made up of stacks of similar straight laminations 2. Laminations 1 and 2 are so arranged that at the corners of the core their ends are in abutting relation, and the adjacent lamination layers have the abutting joints in staggered relation, in accordance with known core construction.

Conventionally, laminations 1 and 2 are so processed that the direction of their grain orientation is along their lengths. Such orientation is diagrammatically indicated in this and the other drawing figures by the parallel lines on each lamination.

In the illustrated core arrangement, such orientation is, except for the corner areas 3, generally parallel to the magnetic flux path in the core. As is evident, the 90° change of direction of the flux path at the corners makes it necessary in the usual case for the flux to travel against maximum resistance (i.e., across-grain) due to the grain structure which throughout the length of the lamination is highly oriented in a single direction.

In accordance with the invention, the regions of the core lamination where the flux path changes to a cross-grain direction, such as at the corners of the core, are subjected prior to the final anneal to a treatment which is capable of impairing the development of highly directional grain orientation which would otherwise be imparted to these regions as a result of the final anneal. These regions, which are shown cross-hatched in FIG. 1 and the other figures of the drawings, are of relatively random grain orientation in contrast to the high degree of grain orientation of the remaining portions of the core laminations, which are shown with parallel lines. Thus, in the FIG. 1 embodiment, only the cross-hatched end regions 3 of each lamination have been subjected to the treatment described to produce random grain orientation therein.

FIGURE 2 is a view showing the application of the invention to another embodiment of a magnetic core arrangement, this construction being constituted by a U-shaped piece 4 comprising portions 4a, 4b, and 4c, and a separate straight member 5 closing the open end of the U-member 4. As will be understood, the final core structure is made up of a stack of the laminations shown in FIG. 2. In a usual procedure, the core laminations 4 and 5 are so rolled during their processing that the grain direction in the entire lamination 4 is parallel to the direction of legs 4a, b, and in the entire lamination 5 is along the length of the piece. Consequently, in practicing the invention, the base portion 4c of member 4 and end portions 5a, b are treated to produce random orientation as shown by the cross hatching therein, in contrast to the substantially unidirectional orientation in the remaining portions of the core members.

In the FIG. 3 embodiment, an E-shaped core member 6 and a complementary straight member 7 are likewise

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treated in accordance with the invention to provide random orientation in base portion 6a of member 6 and portions 7a, b, c of member 7, since it is in these regions that the flux path in the intended operation of the core will travel generally across grain.

FIGURE 4 shows a segmented punching 8 of a generator stator core to which the invention is applied. Since in the usual processing treatment, the entire lamination 8 will have its grain orientation directed parallel to the lines shown in main portion 8a, the teeth portions 8a, b, c, are treated in accordance with the invention to provide random orientation therein to facilitate travel of the flux along the length of the teeth during the normal operation of the stator core structure.

In accordance with the principles of the invention, the core laminations are subjected to a treatment in their semi-finished state, that is prior to the usual secondary recrystallization or grain growth anneal, such that after the latter anneal the regions of the laminations forming the corners of the core and other cross-grain areas have a relatively random grain orientation as compared to the remaining portions of the lamination. There is obtained, as a result, a condition in these regions affording much less resistance to the travel of the magnetic flux therein. It has been found that not only is a marked reduction in the core loss obtained in the core, but also the magnetostriction, which is a basic cause of core noise, is likewise considerably reduced.

The concept of the present invention involves essentially the treatment of selected portions of semi-finished silicon steel (or equivalent magnetic core material) in a manner to impair the ability of only the so-treated portions of the silicon steel to develop a high degree of grain orientation during the usual grain growth anneal to which the material is subsequently subjected. By semi-finished silicon steel is meant silicon steel alloy sheet material, containing about 1-5% silicon (normally about 3% silicon), which has been hot rolled from a silicon steel ingot and subjected to a series of cold rolling and intervening annealing treatments to reduce the gage of the strip (e.g., to 14 mils) and to remove impurities and strain from the material, but which has not yet been given the final anneal (e.g., about 1100° C.) which serves to grow secondary crystals of optimum size and proper orientation and to further refine the steel. In general, the selected portions thus treated are those in which the flux must travel across grain.

In one embodiment of the invention the treatment of the corner portions of the core comprises the physical alteration or deformation of the selected portions. Such physical alteration may be accomplished by applying a tool having a roughened, stippled, or serrated surface with high pressure against the surface of the selected core portions. Other procedures which may be used are embossing, abrading (such as by scratching or grit blasting), rolling under pressure, and various other techniques for physically modifying the selected areas. In addition, the invention contemplates modification of these areas by other means such as by coating the selected areas with suitable materials or other treatments of these areas which have the effect of impairing the grain growth as above described. For example, it has been observed that a coating of magnesium oxide containing 1% of boron in the form of boric acid added thereto will prevent the generation of the usual high degree of preferred orientation during final anneal. Using such a coating on semi-finished silicon steel samples the preferred orientation or texture of the samples was reduced to about 50%, whereas the same steel treated with a magnesium oxide coating containing no boron generated a texture of about 80%.

Other means of achieving the purposes of the invention may include heat treating the desired areas, especially by raising the temperature rapidly in these regions by suitable heating means for inhibiting grain growth of

well-oriented crystals, an effect which is known in the art.

FIGURE 5 shows an embodiment of a means for physically altering the condition of a core lamination to provide random grain orientation therein in accordance with the invention. In this embodiment, the selected portion of the core lamination is subjected to a high compressive force between the roughened or serrated surfaces 10a, 11a, of a base member 10 and a movable member 11. The particular form or arrangement of the serrations is not critical, since it appears necessary only to subject the semi-finished steel portion to pressure of a rough surface to achieve the purposes sought. While the reason that such treatment impairs the orientation capabilities of the lamination portions thus treated is not fully understood, it is conceivable that the crystals of the material are so dislocated from their previously prepared arrangement by the described treatment that the final anneal is not effective to induce a high degree of grain orientation therein.

FIGURE 6 shows another means for carrying out the invention. In this embodiment, the selected portion of the lamination is subjected to a grit-blast treatment, which has also been found to result in substantially lowered cross-grain watt loss in the finally processed lamination. In such treatment the nozzle 12, through which a stream of finely divided grit or sand is forced under pressure by any suitable means, may be moved back and forth over the desired area 14 of the lamination 13 until the surface of the latter is visibly roughened and deformed.

In initial experiments leading to the invention it was found that the normal and predominant texture of silicon steel that is, the (110) [001] orientation of the constituent crystals, as defined by the Miller index system of crystallographic notation, generated during the final anneal of semi-finished core steel could be altered by subjecting the steel to small amounts of face deformation. For this purpose, Epstein strips 14 mils thick and 3 centimeters wide and composed of steel with 3 percent silicon were subjected to deformation by pressing a standard machinist's file against the surface of the strip under various loads. These strips were then annealed along with control (undeformed) strips of the same material. The anneal was conducted in dry hydrogen using an eight hour 1175° C. heat treatment in a furnace. The finished strips were then given the integrated disc test described below to determine the percent texture, i.e., the degree of anisotropy.

The integrated disc test (I.D.T.) involved the use of a spinning disc tester which is an apparatus for the rapid measurement of magnetic anisotropy in sheet or strip material. The tester comprises a motor having a shaft to which is attached a chamber which holds the specimen under test in the form of a thin disc. The disc is spun at a uniform speed about an axis normal to the surface of the disc and passing through its center. The device also includes a magnetic circuit which provides a constant field parallel to the plane of the disc, a set of search coils arranged about the disc in such manner that any change in the magnetic flux passing through the disc will produce a voltage in the coils, and an oscillograph or other device for detecting any voltage developed across the search coils due to flux variations through the disc. The instrument is calibrated by measuring the voltage developed by specimens whose magnetic anisotropy had been determined by known methods. Since the degree of magnetic anisotropy is a function of the amount of texture, i.e., crystal orientation in the sheet or strip, it is possible to calibrate the spinning disc tester in terms of crystal orientation. The data presented in the table below were obtained from an instrument so calibrated and are in terms of a percentage of perfection that was obtained. Perfection was considered to be a disc which had been prepared from a single crystal of the material under examination and oriented in the rolling direction.

The following table shows the results obtained in the above test using untreated control samples and samples to which various pressures were applied:

Table I

Sample designation	Conditions used in deformation	Percent texture
10 a-2	No deformation—control sample	91.7
a-1	Pressure 37,200 p.s.i.—coarse serrations	70.1
b-2	No deformation—control sample	91.9
b-1	Pressure 37,200 p.s.i.—fine serrations	75.6
c-2	No deformation—control sample	89.9
c-1	Pressure 54,400 p.s.i.—coarse serrations	62.7
d-2	No deformation—control sample	90.6
d-1	Pressure 54,400 p.s.i.—fine serrations	72.4
15 e-2	No deformation—control sample	90.6
e-1	Pressure 108,800 p.s.i.—coarse serrations	45.8
f-2	No deformation—control sample	88.5
f-1	Pressure 108,800 p.s.i.—fine serrations	57.6

¹ Based on projected area.

From the above data it is evident that the grain orientation in the silicon steel strips was far less pronounced in those cases where the strip was face-deformed (before annealing) in the manner described. It was also noted that no substantial change in the shape or size of the laminations was observable as a result of the surface deformation by the pressing procedure.

In further experiments four commercial lots of 14 mil semi-finished silicon steel strip were selected, these strips being across-grain, i.e., the rolling direction was transverse the length of the strip. These strips were pressed under a loading of 30 tons per sq. inch using serrated plates of the general construction shown in FIG. 5 in contact with the strip surfaces. The following data for across-grain core loss, across-grain magnetostriction, and texture in the rolling direction were obtained; the core loss being given in watts per pound at the specified flux density B, and the magnetostriction being in terms of parts per million at the specified flux density:

Table II

Lot No.	X-grain core loss w.p. at 15000B for—		X-grain magneto- striction p.p.m. at 15000B for—		Texture in percent for—	
	No load	60,000 p.s.i.	No load	60,000 p.s.i.	No load	60,000 p.s.i.
2321	1.729	1.417	3.52	1.10	90.7	30.1
9305	1.949	1.603	10.60	5.25	92.3	29.5
7537	1.873	1.582	9.88	5.00	92.7	21.9
7575	1.845	1.416	9.08	1.30	91.7	26.9
Avg.	1.849	1.505	8.27	3.18	91.8	27.1

For determining the magnetostriction characteristics, the sample was tested in a device which was calibrated in terms of the linear dimension change which is undergone by the sample under excitation. The core loss measurements were taken by a standard procedure well-known in the art and the percent texture in the above table is that for the rolling direction of the samples and was determined by the above described procedure.

The above data clearly demonstrates the advantages accruing from the alteration of texture in the cross-grain regions of a core lamination. As indicated, the cross-grain core loss drops by nearly 20%, and the magnetostriction is reduced by about 60% over the values normally obtained. The considerable impairment of texture in the rolling direction by the described procedure is also evident from the above results.

In a further test carried out to demonstrate the effect of an abrading treatment of the type shown in FIG. 6, a number of semi-finished silicon steel sample strips were subjected to a grit-blast treatment wherein grit was directed against the surface of the strips from a hand nozzle held about 1 inch from the surface. The nozzle was

moved back and forth over the strip surface until the entire strip surface was roughened by the impingement of the grit. These strips and another group of strips cut from the same lot of steel but which had not been grit-blasted were then dusted with aluminum oxide and annealed at 1175° C. for eight hours in a dry hydrogen atmosphere. The two groups of strips were then assembled into separate packs and tested for core loss at 15000B. It was found that the cross-grain core loss of the strips subjected to grit blasting was 1.33 watts per pound, whereas the core loss of those not so treated was 1.56 watts per pound, showing that a substantial reduction in core loss is achieved by the grit-blasting treatment.

A typical process which may be employed in carrying out the invention is as follows, it being understood that the specific procedure is given by way of example only:

Raw iron scrap containing the usual proportion of impurities such as phosphorus, sulfur, chromium, nickel, aluminum, and copper, as well as manganese, is melted in a furnace and about 1 to 5% by weight of silicon (preferably about 3¼%) is added thereto. With the temperature of the melt adjusted to about 1600° C., the mixture is poured into an ingot mold. After solidification, the ingot is hot rolled to a strip 100 mils thick, and then rolled to an intermediate gage, e.g., 30 mils. The strip is then heat treated in an open anneal, cooled and cold rolled to the desired final gage. The strip is then decarburized by heat treatment in wet air at 800° C. At this stage, the selected portions of the strip are subjected to a pressure with a serrated tool of about 60,000 lbs. per sq. inch, and thereafter the thus treated strips are subjected to anneal at about 1100° C. for about 8 hours or a sufficient period to grow secondary crystals of optimum size and proper orientation and to further purify the strip by the removal of residues of carbon, sulfur, oxygen and other impurities.

From the foregoing description, it is evident that the invention provides for considerable improvement in magnetic and electrical properties of core laminations by the use of a simple, economical and convenient process, whereby it is possible to selectively generate improved cross-grain properties in any predetermined area of semi-finished magnetic steel. At the same time, the process is such that it does not adversely affect the normally excellent with-grain properties of the material in those areas where they are desired.

The expressions "sheet material" and "sheet" as used in the appended claims are intended to include such forms as sheets, strips, tapes, and other laminar shapes.

While the present invention has been described with reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the scope of the invention. Therefore, the appended claims are intended to cover all such equivalent variations as come within the true spirit and scope of the invention.

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

1. A magnetic core comprising sheet material consisting of elongated portions extending at an angle to one another and intersecting to form a corner, at least one of said portions being highly grain oriented along most of its length, at least one of said portions having random grain orientation in the region of said corner to provide reduced resistance to the passage of magnetic flux in said corner region.

2. A magnetic core comprising sheet material consisting of elongated portions extending at an angle to one another and intersecting to form a corner, at least one of said portions being highly grain oriented along most of its length, at least one of said portions having random grain orientation in the region of said corner to provide reduced resistance to the passage of magnetic flux in said corner region, only said corner region having a physically deformed condition for producing such random orientation.

3. A magnetic core comprising sheet material consisting of elongated portions extending at an angle to one another and intersecting to form a corner, at least one of said portions being highly grain oriented along most of its length, at least one of said portions having random grain orientation in the region of said corner to provide reduced resistance to the passage of magnetic flux in said corner region, only said corner region having a coating thereon for producing such random orientation.

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