July 4, 1939. F. BITTER 2,165,027

PROCESS FOR PRODUCING MAGNETIC SHEET

Filed Nov. 21, 1935

Fig. 1.

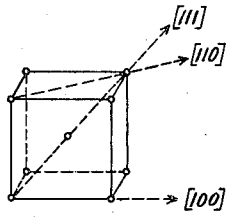


Fig. 2.

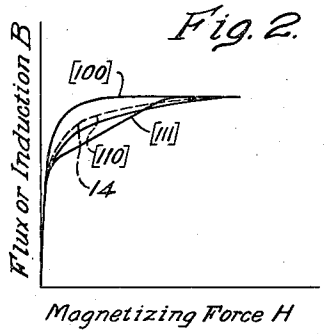


Fig. 3.

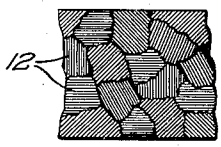


Fig. 4.

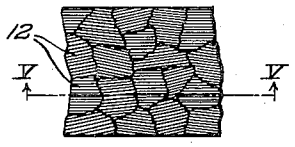


Fig. 5.

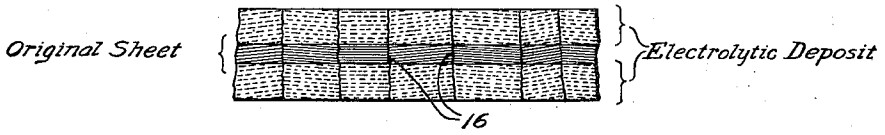


Fig. 6.

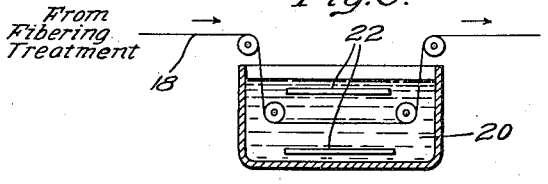


Fig. 7.

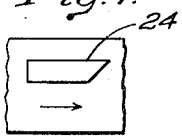
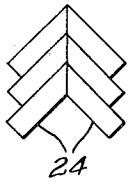


Fig. 8.



WITNESSES:
C. J. Weller,
C. F. Bryant

INVENTOR
Francis Bitter.
BY
Ezra W. Savage
ATTORNEY

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2,165,027

PROCESS FOR PRODUCING MAGNETIC SHEET

Francis Bitter, Cambridge, Mass., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

Application November 21, 1935, Serial No. 50,862

2 Claims. (Cl. 204—1)

My invention relates to the production of electrical sheet material of high magnetic quality, and its has particular relation to a process, involving electrolytic deposit, for producing magnetic sheet which at high flux densities exhibits enhanced permeability and other magnetic properties.

Laminated magnetic material intended for use in constructing the cores of transformers, dynamo-electric machines and other comparable electrical apparatus should preferably possess high permeabilities at high flux densities since for a given apparatus capacity the higher the permeability the smaller the core dimensions. In the interests of efficiency the ideal material should also have relatively low power loss characteristics.

The electrical steel of commerce today is a ferrous-base alloy which is processed into sheets of a thickness of the general order of 0.014 inch. Preferred compositions consist of a predominating proportion of low-carbon steel and from about ½ to 5% of silicon.

It is recognized that the sheet of a given ferromagnetic material having the highest permeability at high flux densities is that in which the grains are so oriented that the direction of easiest magnetization through the grain crystals coincides with the direction of magnetization of the sheet. Processes for producing such preferred grain orientation are now known. Certain of these, to be discussed more fully later, are especially effective in giving the above-stated combination of high-density high permeability and low losses.

Generally stated, the object of my invention is to increase the effectiveness of these processes and to extend their ultimate possibilities.

A more specific object is to supplement them by an electrolytic treatment whereby the thickness of a grain-oriented base sheet may be built up without destroying the preferred arrangement of the grains.

Another object is to provide means whereby more of the same material may be electrolytically deposited on the surface of a base sheet in such a way that the grains already present are continued in the deposit.

A further object is to provide means whereby grain-orienting processes dependent upon thickness reduction may be carried to a far more complete degree than heretofore possible.

In practicing my invention I achieve the above-stated objects by first imparting to a base sheet, by a treatment involving thickness reduction, a grain orientation which enhances the desired magnetic characteristics and then increasing the sheet thickness by electrolytically depositing more of the same material upon the sheet surface in such a way that the grains already present are continued in the deposit. The grain-orienting treatment may then be applied to the built-up sheet to further perfect the fibering or preferred arrangement of the grains.

My invention itself, together with additional objects and advantages thereof will best be understood through the following description of specific embodiments when taken in conjunction with the accompanying drawing, in which:

Figure 1 is a representation of the manner in which the atoms are arranged in a single crystal of magnetic material of the class typified by iron;

Fig. 2 is a diagram of curves illustrating certain magnetic characteristics of the crystal of Fig. 1;

Figs. 3 and 4 are representations of magnetic materials respectively having a random and a preferred orientation of the axes of their grain or crystal structures;

Fig. 5 is a view in section taken along line V—V of Fig. 4 showing the grain boundaries of the original sheet and indicating how these boundaries are continued in a surface deposit when electrolytically made in accordance with my invention;

Fig. 6 is a simplified representation of one form of electrolytic cell by means of which the surface deposit may be made; and

Figs. 7 and 8 are views illustrating how sections coincident with the direction of easiest magnetization may respectively be cut from a base sheet and so interfitted together that an electrolytic deposit thereon produces sheet material having irregular or other predetermined paths of easy magnetization.

In explaining my invention, consideration will first be given to the characteristics of a single crystal of ferro-magnetic material the cubic structure of which is represented in Fig. 1. This crystal, which has an atom positioned at each of the eight corners thereof and another atom at the center, is typical of materials, including silicon steels, of the so-called iron class.

The curves of Fig. 2 depict how the magnetic properties differ along different of the crystal axes. The direction of easiest magnetization, to which the curve 100 applies, is along any one of the three tetragonal axes, one of which is indicated in Fig. 1 at 100. Each defines a direction perpendicular to a face of the structure.

Ranking next is any one of the directions from one corner of a face to a diagonally opposite corner of the same face. The diagonal axis of one such direction is indicated in Fig. 1 at 110 which symbol also designates in Fig. 2 the applicable magnetization curve. Ranking last in order of magnetizability, as typified by curve 111 of Fig. 2, is any one of the directions diagonally through the cube determined by any one of the trigonal

axes drawn from one corner of the structure to the diagonally opposite corner.

Crystals not only of pure iron, but also of alloys of iron with small amounts of any element that will go into solution therewith exhibit the characteristics of Fig. 2. Examples of such elements are silicon, which as already indicated at the present time finds greatest commercial application in ferro-magnetic materials and also aluminum, nickel, copper, manganese and others.

When conventionally prepared, magnetic sheet is of the non-fibered or randomly oriented grain variety typified by the magnified-surface representation of Fig. 3 in which each of the cross-hatched areas 12 represents an individual grain of the metal. Each of these grains is made up of a large number of the cubic crystal structures previously described, which are arranged side-by-side in a regular or parallel manner. In effect, therefore, each grain assemblage exhibits magnetic characteristics comparable to those of the individual crystal structures of which it is made up.

In Fig. 3 the parallel lines drawn through each of the grain areas 12 indicate the direction of easiest magnetization through the grain. When randomly oriented, as in Fig. 3, distribution of the grain axes is substantially the same in all directions and no particular direction can, therefore, be said to be preferred. For such a condition the highest attainable magnetic property may be expected to be of some average order such as is indicated by the dotted curve 14 of Fig. 2.

When, however, as is indicated by the showing of Fig. 4, certain of the axes of the grains 12 are all lined up in substantially the same direction, a condition spoken of as fibering, the material is found to exhibit preferential directions of easy magnetization, which directions are taken advantage of in the practice of the present invention.

Processes for producing preferred grain orientation (Fig. 4) are known. One found to be especially effective is the strain-annealing treatment more fully described in a copending application, Serial No. 750,930, filed November 1, 1934, in the names of Albert A. Frey and myself. In this treatment an especially advantageous form of grain orientation is attained by subjecting the ferro-magnetic material sheet during its final stages of thickness reduction to one or more specially predetermined cycles of strain introduction and annealing, which combine to produce a well fibered material having large grains due to recrystallization.

The strains may conveniently be introduced by a conventional rolling operation carried on at a temperature below that of recrystallization. To be most effective this rolling should preferably effect a reduction in sheet thickness of from about 30 to 60%. The annealing operation is preferably carried on at a temperature of the general order of from about 700° C. to 1300° C. for a period which, depending upon the nature of the material and certain other factors, may vary from a minimum of several seconds to a maximum of several hours.

The rolling so strains the material crystals that the subsequent annealing in relieving the strains appears to orient the crystals with the lateral edges of the cubic structures (and hence certain of the 100 axes thereof) substantially parallel to the direction of rolling. The result is sheet material which exhibits both the highest permeability and lowest loss characteristics in the direction of rolling.

Another process for orienting the material grains consists of a cross-rolling treatment more completely described in my copending application Serial No. 744,516, filed September 18, 1934. In that process the material is reduced to its final thickness by rolling in two different directions which are displaced from each other by substantially 90°. The best magnetic properties of the sheet thus treated are in a direction displaced 45° from these directions of rolling. The type of orientation here resulting is that in which the 100 axes of the crystal structures of the ferro-magnetic sheet are aligned in a direction displaced by 45° from the directions of sheet rolling.

Both of the grain orienting processes above described involve reduction of sheet thickness and in many instances their effectiveness is limited by the fact that this reduction cannot be carried substantially further than the more or less standardized 14 mil value of final sheet size, a value which represents a compromise between a dimension above which the sheet eddy current loss is excessive and a lower limit which is dictated by the cost with which the sheets may be made and handled.

For the above and other reasons a need exists for a process whereby the thickness of grain-oriented base sheets may be increased without destroying the original orientation. The process of my invention now to be described is capable of accomplishing this result.

Basically it comprises a method of building up a grain-oriented or other sheet by so electrolytically depositing more of the same material on the sheet surface that the grains already present are continued in the deposit. In consequence the deposit has the same orientation as the sheet on which the deposit was made. This is best illustrated by Fig. 5 in which the section between the two central horizontal lines represents the original or base sheet which has ben subjected to a grain-orienting treatment which aligns the axes of easiest magnetization substantially all in the same direction as indicated in Fig. 4. The two outer sections of the representation typify material added to the upper and lower surfaces of the original sheet by a special process of electrolytic deposit. It will be observed that the boundaries 16 of the base sheet grains are continued in these deposits.

In my experiments I have found that to produce in iron this form of grain growth by electrolysis, it is preferable to immerse the originally fibered sheet 18 in an electrolytic cell of some form, such as is shown in Fig. 6, which contains a bath of liquid 20, preferably compounded in accordance with the formula below presented. One or more electrodes 22 immersed in the bath supply the metal which is deposited upon the base sheet surfaces. These electrodes are connected to the positive side of a suitable direct-current source of power (not shown) while the sheet 18 being treated is connected with the negative side of the same source in order that it may constitute the cathode of the represented plating apparatus.

In preparing the solution 20 I have found that the following ingredients may satisfactorily be used:

Electrolytic iron	grams	227
Hydrochloric acid having a concentration of 35%	cubic centimeters	720
Water	do	1090
Calcium chloride	grams	900

A bath operating temperature of about 90 to 100° C. is found to be satisfactory. The current passed through the bath is preferably so regulated as to give a density of from 14 to 19 amperes per square foot of base sheet surface being plated. Grain growth is found to occur only when the hydrogen ion concentration (pH value) is kept lower than is usually the case in a bath of the composition above particularized. During satisfactory operation of the cell an analysis made of a sample of the bath showed the following characteristics:

	Grams
Fe'' (ferrous ions) per cubic centimeter	0.063
Fe''' (ferric ions) per cubic centimeter	0.0004

pH vaue of 4.6.

As previously specified, the original sheet 18 may first be given any type of grain orientation desired. When subjected to the treatment just described this orientation will be reproduced throughout the material which constitutes the surface-deposited thickness. The original or a supplemental fibering process may then be applied to the sheet thus built up to further perfect the grain orientation and provide a product of marked superiority.

The grain growing process above described is found to be very successful with pure iron as well as with other materials which can be deposited electrolytically. The before-referred to cross-rolling process which aligns the 110 axes of the crystal in the rolling directions is capable of application to such unalloyed iron. Likewise, the strain annealing process which produces superior magnetic properties in the direction of the rolling may be applied to unalloyed iron provided the annealing temperature is kept below the "gamma transformation" point at which the body-centered cubic lattice which exists at room temperature goes over into a face-centered lattice. For pure iron this takes place at about 910° C. Practical methods for preferentially orienting the grains in a base sheet of unalloyed iron are, therefore, available.

As indicated by the above observations, the present invention is capable of producing a wide variety of results. As already pointed out, the iron may be deposited electrolytically on a base sheet originally fabricated in any manner desired, and the grain orienting process involving thickness reduction may be repeated as often as desired to further perfect the crystal arrangement. In case it is desired to have good magnetic properties in two different directions, this may be done by utilizing the cross-rolling process, or by cutting from a sheet of strain annealed material, represented in Fig. 7, a plurality of sections 24 which coincide with the direction of sheet rolling indicated by the arrow, and then arranging these in the manner shown in Fig. 8 to form a base pattern, the thickness of which may be built up by the electrolytic treatment above discussed.

This method is not restricted to the straight line sections illustrated since from a piece of material having good magnetic properties in one direction, pieces may be cut out having any desired shape with respect to the orientation, and then fitted together as desired to produce any curved or even broken line in the sheet which possesses superior magnetic properties. This modification is especially useful in producing L plates from material originally oriented by the described strain-annealing treatment.

While at the present time it is not practical to electrolytically deposit alloys of iron with silicon, magnetic sheets may, nevertheless, be made up in accordance with my invention to possess in their final form the desired quantity of silicon.

The silicon may, for example, be added by heating the electrode after deposition in the presence of chemical compounds containing the silicon or other substances desired. The heating must, of course, be carried on in such a way that these substances diffuse into the electrode in the desired proportion.

A still further method is to cause the alloying substances to be present in the electrode when the electrolysis is begun and after the deposit is completed, to uniformly diffuse them throughout the iron by means of a suitable heat treatment.

It will, therefore, be apparent that the process of my invention involving preservation of grain arrangement by electrolytic deposit is capable of many practical applications in the art of electrical sheet fabrication.

Although I have shown and described certain specific embodiments of my invention, I am fully aware that many modifications thereof are possible. My invention, therefore, is not to be restricted except insofar as is necessitated by the prior art and by the scope of the appended claims.

I claim as my invention:

1. The method of producing ferro-magnetic sheet material of high magnetic quality which comprises imparting a preferred grain orientation to a base sheet of material determined by the direction of rolling during its thickness reduction, then increasing this thickness by electrolytically depositing iron on the surface of the base sheet from a bath containing hydrochloric acid, substantially 0.063 gram of ferrous iron per cubic centimeter, 0.0004 gram of ferric iron per cubic centimeter, and a pH value of substantially 4.6, by passing an electrical current through said bath of a density of susbtantially from 14 to 19 amperes per square foot of base sheet surface and then reducing the thickness of the resulting sheet by rolling to orient the grains of the added material in a direction corresponding to the orientation of the grains in the base sheet.

2. In the method of making ferro-magnetic material having improved electrical properties, the steps consisting of reducing the thickness of the material of a base sheet by a plurality of rolling operations each of which effects a reduction in thickness of between 30% and 60% and thereby introducing strains into the material and following each of said rolling operations by a heat treatment which relieves these strains and orients the crystallographic axes of the sheet material grains which offer the least resistance to magnetization in a direction substantially coincident with that in which the sheet was rolled, then increasing the thickness by electrolytically depositing iron on the surface of the base sheet from a bath containing hydrochloric acid, substantially 0.063 gram of ferrous iron per cubic centimeter, 0.0004 gram of ferric iron per cubic centimeter and a pH value of substantially 4.6, by passing an electrical current through said bath of a density of substantially from 14 to 19 amperes per square foot of base sheet surface and then reducing the thickness of the resulting sheet by rolling in the same direction as the base sheet to orient the grains of the added material to correspond to direction of orientation of the grains of the base sheet.

FRANCIS BITTER.