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METHOD OF RENDERING AN ALUMINUM-IRON ALLOY DUCTILE

Joseph F. Nachman, Silver Spring, Md., assignor to the United States of America as represented by the Secretary of the Navy

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to a magnetic material and more particularly to a new and improved method of making the same into ductile and workable sheet and tape form.

Aluminum-iron alloy heretofore used exhibited excellent electrical and magnetic properties. However, because of the inherent brittle characteristic thereof the material was not used extensively for the reason that it was impossible to be cold worked into sheet form without breakage thereof.

The present invention contemplates the provision of a new and improved method of making such material into a workable strip which is sufficiently tough and ductile to be sheared into any desired shape without damage or breakage. Furthermore, the new and improved method produces a magnetic material having the desired magnetic characteristics and which possesses isotropic magnetic properties and high bulk resistivity thereby preventing electrical losses. Moreover, in accordance with the new and improved method it has been found that the material developed or grew its own insulating layer and thus in various magnetic applications, the usual insulating fabrication process could be eliminated. In certain other applications it has been found that the magnetic material produced by the new and improved method is far superior to the hot worked aluminum-iron alloy now in use. Furthermore, in transformer cores of the type used in high frequency communication instruments, it has shown properties far superior to those shown by the silicon iron cores now so extensively used in such instruments. Furthermore, while alloys of the aforesaid type have been heretofore used no successful method has been devised for working such alloys into thin sheets or tapes having the desired ductility or malleability to render them commercially useful, particularly if such alloys contained aluminum in excess of 5%. In accordance with my discovery it is possible to reduce such sheets having up to 16% aluminum into relatively thin tapes having improved electrical characteristics and also reduce the brittleness thereof sufficiently to permit the tapes to be readily bent into any desired shape without causing breakage thereof.

An object of the present invention is to improve the present methods of manufacturing Al-Fe sheets such that sheets having an aluminum content in excess of 5% may be readily rolled into tape-like form without the losses in yield now encountered because of the lack of ductility or malleability of the sheets made under the present hot working methods.

Another object of the invention is to provide a method of making brittle aluminum-iron alloy into workable sheet or tape-like form.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same

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becomes better understood by reference to the following detailed description.

In the process of making the aluminum-iron alloys into workable strips or tapes in accordance with the present invention, the iron is melted in a suitable furnace such, for example, as a high frequency furnace. After melting the iron the aluminum is added thereto. After allowing sufficient time to permit proper mixing of the aluminum and iron the temperature is regulated and the melt is cast into a slab mold designed to produce a fine, preferably an equiaxed grain structure. The slab is then reduced in thickness by hot rolling at temperatures between 1000° C.-1050° C. from 1" to substantially 0.250", the last or final hot rolling operation to a thickness of 0.125" being conducted at about 900° C. in order to obtain full benefit from the grain refinement occurring at the lower temperature.

With reference to the article "The lattice spacings of iron-aluminum alloys," by A. J. Bradley and A. H. Jay, Journal of Iron and Steel Institute [London], pages 339 to 361 of volume 125 [1932], and as illustrated in page 1161 of the Metals Handbook, 1948 edition, published by American Society for Metals, it has been determined that the region of order-disorder transformation occurs in aluminum-iron alloys having an aluminum content of 10 to 20%. Therefore, alloys containing from 10 to 20% aluminum have a tendency to order into an Fe₃Al type lattice, which is believed to be mechanically softer than the disordered phase. However, although alloys containing 5 to 10% aluminum are not fully characterized by the Fe₃Al type lattice, it was discovered that working these alloys in the order-disorder temperature range enhanced the ductility thereof and made feasible a reduction in thickness without breakage. Thus if the aforesaid 0.125" material is rolled on down in the order-disorder temperature range, which lies in the neighborhood of 450° C. or somewhat below 600° C., with the alloy maintained in this ordered or partly ordered condition it is sufficiently ductile to enable rolling the material to any desired thickness. In the specification and the appended claims, the order-disorder temperature range shall be construed to include temperatures within the range of 450° C. to 600° C. The cold rolling at elevated temperatures employed with the improved method was conducted at average temperatures of 500° C., 550° C. and 575° C., the latter being the most desirable and produced admirable results. The temperature variations of the furnace during the on and off cycles was 550° C. to 600° C. whereupon an average temperature 575° C. was obtained. This technique was carried out by allowing the alloy to heat for a few minutes between passes of the material through a suitable rolling mill in order to maintain the alloy at a temperature of approximately 575° C. during the cold-rolling process. A strip furnace may be employed, if desired, to speed up the aforesaid heating and rolling cycles. By the cold rolling method, sheets from 0.014" to 0.00035" in thickness was produced.

It has been found that sheets or strips approximately 0.007" thick produced in the aforesaid manner and heated at 575° C. for a short period of time gave admirable results. Also, sheets recrystallized with a minimum grain size have produced admirable results. These sheets may be cut into strips 3/8" wide and the oxide coating removed to minimize wear during the rolling operation as the strips were rolled at room temperature on a conventional mill to a thickness of substantially 0.002 of an inch. When this operation has been completed the edges of the 0.002" strips are removed yielding strips 1/4" wide and thereafter rolling operation continued at room temperature until the strips are reduced in thickness to about 0.0005 of an inch thereby to form a thin tape. It has been found that the strips may be successfully rolled

into the aforesaid tape form without employing the annealing process and still maintain its workable characteristics.

It has been further discovered that the finished sheet rolled at 575° C. develops a surface coating of essentially aluminum oxide which is not effectively reduced by a high temperature anneal in hydrogen. In fact, the quality of the aforesaid insulation appears to improve when the sheet is subject to the high temperature hydrogen anneal. Furthermore, if desired, heavier coatings of aluminum oxide may be formed on the aforesaid sheets by annealing first with wet hydrogen followed by annealing with dry hydrogen. Moreover, in instances where the oxide coating has been removed from the tape prior to additional rolling it may be preoxidized in a conventional furnace to restore the coating which makes it admirably suited for winding the tape into a toroidal core, it being understood that the thickness of the oxide insulating coating will be a function of the temperature, time, and type of atmosphere employed. The advantages of the thin surface oxide coating especially on the thin tape will obviously facilitate stacking of the tape since the tape is well insulated by the aforesaid coating and thus during a stacking operation the usual insulating spaces heretofore may be eliminated.

Furthermore, it has been found by actual test that the magnetic properties of the material produced by the aforesaid method and containing nominally 16% aluminum and 84% iron is far superior in magnetic properties found in material produced by the hot rolled method alone which contains like amounts of the aforesaid alloys. For example, the magnetic properties obtained in a core structure employing magnetic sheet produced in accordance with the present invention wherein the sheet is 0.014 of an inch thick with the ring laminations (2" O. D. x 1½" I. D.) is set forth in the following example: $\mu_m=115,880$, $\mu_o=2,778$, $H_c=0.024$, $B_r=4,192$, and $B_m=7,608$ in comparison with the magnetic properties of a core structure produced in accordance with the aforesaid hot rolled method and set forth in the following example: $\mu_m=55,000$, $\mu_o=3,100$, $H_c=0.04$, $B_r=2,100$.

Furthermore, the high resistivity of 140-150 microohm-cm. found in the new and improved magnetic material is substantially 3 times greater than that found in silicon-iron alloys heretofore used. Moreover the core losses in the improved magnetic material is substantially small compared to losses of commercial silicon-iron alloys. For example: a 60 cycle core loss of 0.04 watt/lb. for 0.014" thick material at a flux density of 5000 gauss is substantially ¼ the value of the core losses suffered in a silicon-iron core tested under identical conditions. The improved power maintaining properties and high mechanical hardness of the magnetic material produced in the new method are characteristics which made it admirably suited for use in recording heads wherein resistance to abrasion is essential.

It will be understood that the material produced by the aforesaid method is not highly grain oriented, in reality the material is magnetically isotropic in contradistinction to the anisotropic material produced by the silicon-iron alloys. Furthermore, the present invention does not relate to austenitic alloys. The high Al-Fe series found in the aforesaid material is body centered cubic in crystal structure at high and low temperatures. Moreover, it is well known to those skilled in the art that the crystal structure of material directly affects workability thereof in response to both heat and cold. Cold rolling denotes cold working of the alloy at a temperature below the recrystallization temperature, whereas hot rolling denotes hot working the alloy at a temperature above the recrystallization temperature. In hot rolling process, for example, the metal is recrystallized, while in cold rolling process, the crystal structure remains the same and the crystals are elongated. Furthermore, it will be understood that in the aforesaid proc-

ess of reheating to the order-disorder temperature range brings about some ordering of the basic Al-Fe alloy lattice thereby to produce a ductile structure which may be cold rolled to a thin tape having a thickness of 0.00035 of an inch, if desired.

The aforesaid new and improved method produces a magnetic material having high resistance characteristic to corrosion particularly when subjected to strong oxidizing solutions such, for example, as concentrated HNO₃ and also to atmospheric oxidation at elevated temperatures and room temperatures.

An alternate method for reducing the aluminum-iron alloy to a thickness of 0.00035 of an inch is as follows:

Roll the material at 575° C. from 0.125 of an inch to 0.028 of an inch; anneal at 575° C. for a short time to produce partial ordering thereof; roll from 0.028 of an inch to 0.014 of an inch at room temperature and thereafter anneal the 0.014 of an inch material at 575° C. for a short time; roll at room temperature from 0.014 of an inch to 0.007 of an inch and anneal the strip of 0.075" material for a short time at 575° C.; the final operation consisting of rolling the strip of 0.007" material to a thickness of 0.00035 of an inch at room temperature.

The following method has also produced admirable results:

Roll the material to 0.014 of an inch by the hot and subsequent cold rolling process hereinbefore described in obtaining a sheet of 0.014" in thickness; followed by alternately heating the material at 575° C. for 5 minutes and rolling the material at room temperatures with one or two light passes through a suitable mill until the desired thickness thereof has been obtained. This method indicates that the 5 minute heating at 575° C. is sufficient to produce enough softening to allow the rolling to continue until the desired thickness of the material is obtained.

From the foregoing, it will be apparent that a new and improved magnetic tape and method of making the same has been discovered wherein the tape is characterized by a tough fibrous structure making it sufficiently ductile to be formed into suitable shapes without breakage or damage thereto and which possesses superior magnetic properties, low power losses, and high resistance to corrosion.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed as new and desired to be secured by Letters Patent in the United States is:

1. The method of making ductile sheets or tape-like magnetic strips from an alloy having nominally 16% aluminum and 84% iron, which consists of forming the alloy into slabs, hot working the slab above the recrystallization temperature to a predetermined thickness, and cold working the sheets in the order-disorder temperature range to a second predetermined thickness less than said first mentioned predetermined thickness.

2. The method of making ductile sheets or tape-like magnetic materials from an alloy containing from 5 to 16% aluminum and 95 to 84% iron, which consists of forming the alloy into relatively thick sheets, cold working the sheets to a thickness of about 0.028" at a temperature of 575° C., reducing the alloy to a thickness of 0.007 of an inch by subjecting the alloy sheets to alternate operations of rolling at room temperature and heating to a temperature within the order-disorder range, and thereafter rolling the alloy sheets at room temperature to a thickness of 0.00035 of an inch.

3. The method of making ductile sheets or tape-like magnetic strips from an alloy containing from 5 to 16 percent aluminum and the remainder iron which consist of forming the alloy into relatively thick slabs, hot working the slabs into sheets of a first predetermined thickness,

cold working the sheets to a second predetermined thickness at a temperature of about 575° C., maintaining the sheets at said temperature for a short time, and thereafter reducing the thickness of the sheets by alternately heating and cold working the sheets.

4. In a method of making isotropic magnetic material in sheet or tape-like form, the steps including hot rolling an aluminum iron alloy of 5 to 16 percent aluminum content and about 1" thick to a thickness of about 0.125" at a temperature of substantially 1000° C., cold rolling the slab at a temperature of about 575° C. to a thickness of about 0.007", heating the sheet at 575° C. for a short time, and thereafter rolling the sheet at room temperature to a thickness of substantially 0.002 of an inch.

5. In a method of making magnetic material into tape-like form, the steps including hot rolling aluminum-iron slabs containing from 5 to 16 percent aluminum into strips at a temperature of about 1000° C., cooling the heated strips to below the recrystallization temperature, cold rolling the strips below the recrystallization temperature into tape-like form, heating said tape to about 575° C., and further rolling the tape at room temperature until the desired thickness is obtained.

6. The method of claim 1 further consisting of working the sheets at room temperature to a desired thickness less than said second predetermined thickness.

7. The method of making magnetically isotropic sheets or tapes from a melt containing from 5 to 16 percent aluminum and 95 to 84 percent iron, which consists of casting the melt into relatively thick sheets, hot working the sheets to a first predetermined thickness, cold working the sheets to a second predetermined thickness less than said first predetermined thickness, and thereafter reducing the sheets to a desired thickness by subjecting the sheets to alternate operations of working at room temperature and heating to a temperature within the order-disorder temperature range.

8. A method for making ductile magnetically isotropic sheets which comprises producing a melt consisting of 5 to 16 percent aluminum and the remainder iron, forming the melt into slabs, hot working the slabs above the recrystallization temperature to a first predetermined thickness, and working the slabs below the recrystallization temperature within the order-disorder temperature range to any desired thickness.

9. The method of claim 8 wherein the working below the recrystallization temperature is performed at an average temperature of 575° C.

10. The method of claim 9 wherein the hot working is performed at an average temperature of approximately 1000° C.

11. The method of claim 8 wherein the working below the recrystallization temperature comprises the steps of rolling the sheets in the order-disorder temperature range to a second predetermined thickness, maintaining the sheets of said predetermined thickness at a temperature within the order-disorder temperature range for a short period of time, and thereafter reducing the sheets to the desired thickness.

12. The method of claim 11 wherein the reducing to the desired thickness is performed by rolling the sheets at room temperature.

13. The method of claim 12 wherein the rolling in the order-disorder temperature range is performed at an average temperature of 575° C. and wherein the temperature at which the sheets are maintained for a short period of time is approximately 575° C.

14. The method for making ductile tape-like magnetic strips which comprises producing a melt consisting of essentially 5 to 16 percent aluminum and the remainder iron, forming the melt into slabs, hot working the slabs above the recrystallization temperature to sheets of a first predetermined thickness, rolling the sheets in the order-disorder temperature range to a second predetermined thickness, maintaining the sheets of said second predetermined thickness at a temperature within the order-disorder temperature range for a short period of time, cutting the sheets into strips of preselected widths, and alternately rolling and trimming the strips at room temperature to desired widths and thicknesses.

15. The method of making ductile magnetic sheets and tape-like magnetic strips which comprises producing a melt consisting of essentially 5 to 16 percent aluminum and the remainder iron, forming the melt into slabs, hot working the slabs above the recrystallization temperature to sheets of a first predetermined thickness, rolling the sheets in the order-disorder temperature range to a second predetermined thickness less than said first predetermined thickness, maintaining the rolled sheets at a temperature within the order-disorder temperature range for a short period of time, reducing the sheets to a third predetermined thickness by subjecting the sheets to alternate operations of rolling at room temperature and heating to a temperature within the order-disorder temperature range, and thereafter working the sheets at room temperature to a desired thickness.

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