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MAGNETIC FLAKE CORE AND METHOD OF PREPARATION

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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.

This invention relates to magnetic cores used with inductance coils, electronic filter networks, resonant circuits, transformers and the like.

More specifically the invention relates to a new magnetic core material and to a method of producing said material and cores from said material.

Prior art magnetic cores have usually been manufactured from Molybdenum-Permalloy either in the form of thin solid material rolled or stacked to produce the desired shape or from the powdered material compacted into the desired shape with an insulation binder. The Mo-Permalloy cores made from the thin solid materials while giving a high value for permeability also give high power losses. The cores made from powdered Mo-Permalloy while giving low power losses also give a low permeability. In addition the Mo-Permalloy cores are prepared from a Permalloy containing about 2% molybdenum, 81% nickel and the remainder iron. The manufacture of these 2-81 Mo-Permalloy cores, therefore, results in the use for this purpose yearly of a considerable tonnage of strategically important, scarce and expensive nickel and molybdenum.

In addition to the above disadvantages, 2-81 Mo-Permalloy powder cores are sensitive to high humidity and require a protective coating to provide humidity stability. They also require the addition of a component to provide temperature stability. The 2-81 Mo-Permalloy powder cores also require heat treatment in a protective atmosphere. All of the above result in processing complications with attendant increases in costs and in safety hazards.

Attempts to find a suitable alternate or substitute for the 2-81 Mo-Permalloy cores have been heretofore unsuccessful. The general requirements for a powdered core are quite severe and difficult to meet all respects. The core permeability should be reasonably high and stable with respect to changes in frequency, induced flux density, temperature, humidity, time and accidental direct current overloads. Total core losses (eddy current, hysteresis and residual) should be as low as possible. Besides these electrical requirements, the core must be sufficiently strong to withstand handling and shock in manufacture and use. In addition, the core manufacturing process must be economical i. e. the material must be fairly easy to grind, insulate, compact and heat treat.

It is, therefore, an object of the present invention to provide a new and useful magnetic material for use in the manufacture of magnetic cores having high permeability and low power losses.

Another object is to provide a magnetic core material utilizing only non-strategic materials.

A further object is to provide a magnetic core hav-

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ing high permeability and low power losses which contains only non-strategic materials.

A still further object is to provide magnetic cores which are magnetically stable under varying environmental conditions.

Another object is to provide a method of manufacturing a new magnetic core material which is simple and inexpensive.

Still another object is to provide a method of manufacturing new and useful magnetic cores which method is simple, inexpensive and safe.

Other objects and the attendant advantages of the invention will become apparent to those skilled in the art as the invention is disclosed in the following detailed description.

The above mentioned objects are achieved in accordance with the invention by the production of magnetic cores by the compaction of flakes of finely divided high aluminum content iron base alloys.

It has been known for some time that when iron particles are converted into the form of flakes, i. e. shaped particles whose length and width are greater than their thickness, and the flaked iron particles layered uniformly in a die cavity so that they can be compressed while maintaining a high inter-laminary resistance than the permeability of the powdered iron core could be improved and the eddy current losses lowered. The permeability is believed to be improved by the more favorable penetration of the flux at various levels of the applied field. The eddy current losses are believed to be lowered by the presence of a greater number of air gaps perpendicular to the plane of the pressed flake laminates. Because of their high electrical losses, however, flake iron cores have not proved satisfactory for most purposes when compared with other powder cores. Other iron base alloys such as Alfenol having good magnetic properties were considered impossible to roll because of their inherent qualities of hardness, brittleness and lack of ductility.

In accordance with the present invention, powders of the extremely hard and brittle high aluminum content iron base alloys are converted to the flake form, subjected to heat treatment to provide an insulating coating on the particles, compacted to form a core of the desired configuration, and the core heat treated to obtain the desired magnetic properties.

Alfenol type alloys, i. e. iron base alloys having from 10 to 17 percent aluminum content, may be prepared by melting electrolytic iron under a vacuum of about 250 microns and subsequently adding ferroaluminum alloy or aluminum to the molten iron. Small amounts of ferrocenium or ferrotitanium may be added to the melt to embrittle the Alfenol for easier grinding. Alfenol type alloys containing from 10 to 17 percent aluminum may be employed as desired.

High aluminum content Alfenol slabs without embrittling agents are extremely difficult to grind. The chill cast ingots may be ground, however, by placing the ingot between two mild steel sheets and cold rolling them to lumps approximately 1/2 to 1 inch in size. The coarse powder may then be pulverized by prolonged ball milling in a steel mill using hardened steel balls. Preferably the particle size should be minus 30 plus 60 mesh although particles of any desired size may be used.

The particles of Alfenol may be flaked by rolling the hot powder between the rolls of a six inch diameter standard 2-high laboratory rolling mill at a temperature below the melting point of the alloy. The powder is preheated preferably to a temperature between 400-500° C. and vibrated into the rolls which have been preheated to approximately 140° C., thereby resulting in a rolling operation carried out at about 200° C. which temperature has been found to produce the best results.

The flaked Alfenol particles are then sieved to obtain flakes of the preferred size minus 30 plus 60 mesh. If the flake thickness is too large they may be rerolled to obtain a high core permeability. It has been found that the best results were obtained on the Alfenol flakes when the ratio of average particle diameter to the average particle thickness is at least twenty to one.

Because of the high aluminum content Alfenol flakes develop a self insulating coating of chiefly aluminum oxide when heated in air. The temperature and time requirement for developing this insulation depends on the alloy composition and the previous history of the flakes. The heat treatment is preferably carried out at a temperature between 400° C. to 900° C. for a period of from 15 minutes to four hours in air at atmospheric pressure. The higher the temperature the less the time interval required. The heat treatment recommended for 16-Alfenol is one-half hour at 500° C. in air. 13.92 Alfenol requires three hours at 500° C. or one-half hour at 700° C. to establish the insulating oxide coating. At the end of the heat cycle the flakes may be cooled to room temperature to facilitate handling if desired but further processing may also be carried out on the hot particles if desired.

At this point insulating material may be added to the flaked Alfenol to further reduce the power losses with a consequent loss in permeability if it is so desired. Up to 3% by weight of sodium silicate may be added for this purpose or sufficient hydrolyzed tetra-ethylsilicate in ethyl alcohol sufficient to leave a coating of silicon dioxide of up to 3% by weight of the flakes may be used as insulation.

In order to increase the density of the compact and thereby to increase the permeability thereof, and to act as a binder, powdered tin, aluminum, zinc or lead may be added to the flaked Alfenol up to 3% by weight of the total mass. For the smaller mesh size flakes it has been found preferable to add 1% by weight of atomized tin or aluminum powder and thoroughly blend the dry mixture before compacting. The larger mesh size flakes require a material with more bonding power and better insulating qualities. For this purpose 1% by weight of vanadium pentoxide may be added to the flakes in a water slurry. The combination of flake and oxide is thoroughly mixed while wet and the water evaporated by heating the mixture. With this oxide binder a core made from minus 18 plus 30 mesh flake possessed good strength after heat treatment.

Before compacting it is necessary that the flakes be arranged in the die so that their shortest axis is perpendicular to the flux direction. This provides the most favorable magnetic path and the highest resistance to eddy currents. This may be accomplished by allowing the flakes to fall freely into a feed funnel that is revolving at a constant rate.

The molding pressure, preferably from 80-125 tons per sq. in., is applied at right angles to the plane of the flakes. Hardened three section dies are required to withstand the high pressures and for ease of ejection of the pressed core.

After compaction the cores are heat treated to develop the best magnetic properties. The core is heated to a temperature between 400°-800° C. and then cooled rapidly to disorder the magnetic material so as to improve the permeability.

For 16-Alfenol the best heat treatment has been found to be ½ hour at 625° C. followed by a water quench. For 13.92-Alfenol the most favorable was found to be a water quench from 575° C. The method of cooling depends on the composition of the alloys and the properties desired in the core. Where the aluminum content is over 12 percent the core should be water quenched. For aluminum contents less than 12% the core may be water quenched or cooled slowly. In the case of cores having vanadium pentoxide for a binder it is necessary

to heat the cores to 675° C. to melt the oxide and then cool them to 575° C. before quenching.

The basic magnetic properties of cores formed in accordance with the invention may be measured by means of a single layer winding upon a toroidal specimen of the material. The permeability and total losses (eddy current, hysteresis and residual) can be determined from R. F. bridge measurements of the current, inductance and resistance of the toroidal winding. The permeability μ of the core is:

$$\mu = \frac{Dm \times L \times 10^9}{4N^2 A}$$

where L is the inductance of the coil in henrys, N is the number of turns in the test winding, A is the cross section of the core in square centimeters and Dm is the mean diameter of the toroid in centimeters. The flux density B (in gauss) in the core is given by:

$$B = \frac{LI(1.414 \times 10^8)}{NA}$$

where I is the bridge current in ampere R. M. S. The basic equation for the Legg method of core loss separation is:

$$\frac{Rac}{\mu Lf} = aBm + ef + C$$

where "a" is the hysteresis loss coefficient, "e" is the eddy-current loss coefficient, "Bm" equals the maximum flux density in gauss in the core subject to alternating magnetizing force, "f" represents the frequency of alternating current in cycles per second, "R" is the effective resistance of the core in ohms and "c" indicates the remainder or residual loss. Since

$$\frac{R}{\mu Lf} = \frac{2\pi}{\mu Q}$$

the value of

$$\frac{R}{\mu Lf}$$

should be very low for a good core material.

Alfenol flake toroidal cores were prepared in accordance with the invention and compared with 2-81 Mo-Permalloy and Alfenol powder cores. The cores were of a commercially standard size, viz., O. D. 1.060", I. D. 0.580" and about 0.25" thick.

Table I lists the magnetic properties of typical Alfenol flake, Alfenol powder and 2-81 Mo-Permalloy powder cores.

Table I

Material	Binder	μ^*	$R/\mu Lf$ 25 kc.	$a \times 10^6$	$e \times 10^9$	$c \times 10^6$
16 Alfenol Powder -120+200 mesh.	None	107	1,162	16	14	377
16 Alfenol Flake -30+60 mesh.	1% Al	169	1,598	-----	-----	-----
13.92 Alfenol Powder -120+200 mesh.	None	90	1,637	-----	14	-----
13.92 Alfenol Flake -30+60 mesh.	1% Sn	240	958	13	14	460
13.92 Alfenol Flake -18+30 mesh.	1% Sn	343	2,103	-----	30	-----
13.92 Alfenol Flake -18+30 mesh.	1% V ₂ O ₅	308	1,577	11	14	656
Mo-Permalloy -120 mesh.	Ceramic	125	537	1.6	19	30

*B=20.

From the foregoing it may be seen that because of the decreased number of air gaps and the improved demagnetization factor the permeability of the Alfenol cores is greatly increased by flaking.

The Alfenol flake cores, manufactured in accordance with the process of this invention have, therefore, a higher permeability than magnetic powder cores. They have lower losses than magnetic tape or laminated cores. Only non-critical and inexpensive components are needed in making the alloys. No addition agents are required

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to provide insulation. In addition the process of manufacture of the material and the cores from said material requires no protective atmosphere thus resulting in a manufacturing process which is simple and less costly and hazardous than that required for the manufacture of comparative magnetic cores. The flake Alfenol cores are, therefore, high density, high permeability cores suitable as non-strategic alternates for Mo-Permalloy cores for low frequency applications.

It is to be understood that the invention may be practiced otherwise than as specifically described within the scope of the following claims.

We claim:

1. A magnetic material for use in the manufacture of magnetic cores and the like comprising flakes of a ferrous alloy containing from 10 to 17 percent aluminum the balance being essentially iron.
2. The magnetic material of claim 1 in which the flakes are provided with an insulating coating.
3. The magnetic material of claim 2 in which the insulating coating is metallic oxide.
4. The magnetic material of claim 3 in which the metallic oxide coating is substantially aluminum oxide.
5. A magnetic core comprising flakes of an iron base alloy containing from 10 to 17 percent aluminum the balance being essentially iron and wherein the flakes are provided with an insulating coating of aluminum oxide.
6. A magnetic core comprising compacted flakes of an iron base alloy containing from 10 to 17 percent aluminum the balance of the flakes being essentially iron, wherein the flakes are provided with an insulating coating of aluminum oxide and a binder selected from the group consisting of tin, lead, zinc and aluminum is disposed between the flakes.
7. The method of preparing a magnetic material for use in the manufacture of magnetic cores and the like comprising forming flakes of an iron base alloy containing from 10 to 17 percent aluminum, a small amount of embrittling agent selected from the group consisting of ferrocerium and ferrotitanium, and the balance essentially iron, by rolling a powder of the alloy at about 200° C.
8. The method of preparing a magnetic material for use in the manufacture of magnetic cores and the like comprising rolling a powder of an iron base alloy containing from 10 to 17 percent aluminum the balance being essentially iron at a temperature of about 200° C. to form flakes of said alloy.
9. The method of preparing a magnetic material for use in the manufacture of magnetic cores and the like comprising rolling a powder of an iron base alloy containing from 10 to 17 percent aluminum the balance being essentially iron at a temperature of about 200° C. to form flakes of said alloy and heating said flakes in air for a period of from 15 minutes to four hours at a temperature between 400° to 900° C.
10. The method of preparing a magnetic core comprising forming flakes by rolling at about 200° C. an iron base alloy containing 10 to 17 percent aluminum the balance essentially iron, heat treating the flakes of the alloy at a temperature between 400° C. and 900° C. for a period of from 15 minutes to 4 hours to form an

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insulating coating of aluminum oxide on the flakes, adding up to 3% by weight of a metal binder selected from the group consisting of lead, zinc, tin, and aluminum, compacting the flakes into the desired core configuration, and heat treating the compacted flake core at a temperature from 400° C. to 800° C.

11. The method of preparing a magnetic core comprising forming flakes of an iron base alloy containing 10 to 17 percent aluminum the balance essentially iron by rolling a powder of said alloy at about 200° C., heat treating the flakes at a temperature from 400° C. to 900° C. for a period of from 15 minutes to 4 hours, mixing with the flakes a small amount of metal binder selected from the group consisting of tin, zinc, lead and aluminum, compacting said flakes into the desired core configuration, and heat treating the compacted flake core at a temperature from 400° C. to 800° C.

12. The method of preparing a magnetic core comprising forming flakes of an iron base alloy containing 10 to 17 percent aluminum and the balance essentially iron by rolling a powder of said alloy at about 200° C., heating said flakes to a temperature between 400° to 900° C. for a period of from 15 minutes to 4 hours, compacting said flakes into the desired core configuration, and heat treating the compacted flake core at a temperature of from 400° C. to 800° C.

13. The method of claim 12 wherein the compacted flake core is cooled rapidly after heat treating.

14. The method of preparing a magnetic core comprising compacting flakes of an iron base alloy containing 10 to 17 percent aluminum the balance essentially iron and provided with a dense insulating coating of aluminum oxide into the desired core configuration, heating said compacted flake core to a temperature between 400° to 800° C. and rapidly cooling said core.

15. The method of preparing a magnetic core comprising forming flakes of an iron base alloy containing approximately 16 percent aluminum and the balance essentially iron, by rolling a powder of said alloy at about 200° C., heating said flakes to approximately 500° C. for one-half hour, compacting said flakes into the desired core configuration, heating said compacted flake core to approximately 625° C. and water quenching said core.

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