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J. G. FORD

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BONDED LAMINATED MAGNETIC MATERIAL

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Fig. 1.

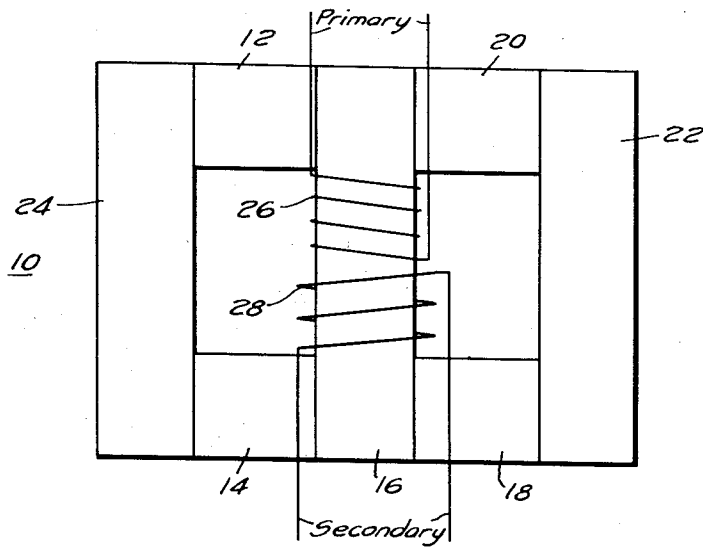
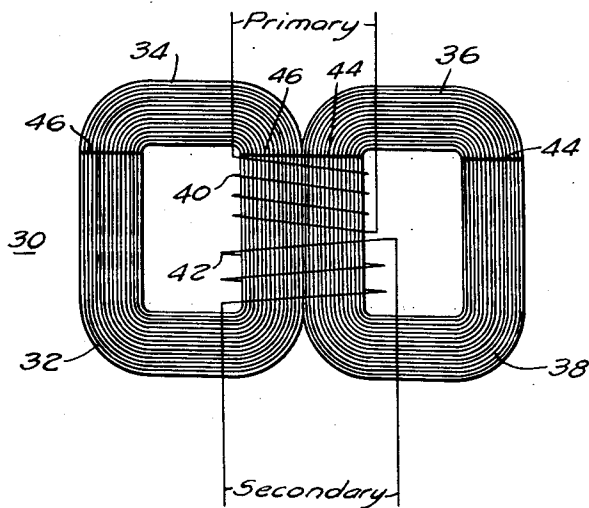


Fig. 2.



WITNESSES:

E. A. M. C. C. C.
Shapoe

INVENTOR

James G. Ford.
Gray & Savage
ATTORNEY

UNITED STATES PATENT OFFICE

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BONDED LAMINATED MAGNETIC MATERIAL

James G. Ford, Forest Hills, Pa., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

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4 Claims. (Cl. 175-21)

This invention relates to bonding, particularly bonding laminations of magnetic material in electrical machinery.

Magnetic material in laminated or sheet form is extensively utilized in the manufacture of a wide variety of electrical apparatus, notably transformers, dynamo-electric machines and other comparable equipment in which substantial quantities of magnetic flux must be linked with electrical conductors. To reduce the size, weight and cost of such equipment, the physical dimensions and losses in the magnetic circuit parts which serve to conduct this flux should be kept as low as possible.

The object of this invention is to provide for bonding cores of magnetic material.

A further object of the invention is to provide a composition for bonding cores of magnetic material.

A more specific object of my invention is to provide for bonding of cores of magnetic material whereby a more efficient electrical apparatus is effected.

The invention accordingly comprises the features of construction, combinations of elements and arrangement of parts which will be exemplified in the construction hereinafter set forth and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which

Figure 1 is an elevational view of a shell-type transformer, and

Fig. 2 is an elevational view of a modified form of transformer.

Magnetic material suitable for use in constructing magnetic circuit parts in electrical machinery comprises silicon steel in which the silicon content ranges from $\frac{1}{2}\%$ to 5% and commonly comes in sheets of a thickness of the order of 0.014 inch. Ordinary silicon steel magnetic material is hot rolled and its price is such that large quantities are used in the building of electrical machinery.

The magnetic properties of hot rolled silicon steel are exceeded by specially processed silicon sheet steel. Magnetic material sold under the trade name of Hipersil is a specially processed silicon steel which has better magnetic properties than the hot rolled material.

This specially processed silicon steel is cold rolled and annealed under such conditions that

the grains in the sheet of steel are so oriented that the direction of easiest magnetization of the individual grains or crystals coincides with the direction of magnetization of the sheet. It has been found that iron, and other magnetic materials having a similar crystalline structure, have grains or crystals which are more easily magnetized along certain given directions. Magnetic material processed to produce a crystal arrangement which gives the sheet of magnetic material substantially the characteristics of the single crystal with regard to ease of magnetization may be said to have a preferred orientation.

The permeability of magnetic steel having preferred orientation is unusually high at a flux density of 16,000 lines per square centimeter. This is an improvement over the performance of hot rolled silicon steel of the same composition.

At all flux densities the steel having preferred orientation has lower watt losses than hot rolled silicon steel.

The processes necessary to produce the high permeability silicon steel entail an increase in the price for this material. It is accordingly desirable, if possible, to employ the improved silicon steel for only a part of the magnetic circuit where its properties may be taken advantage of and combine with it the less expensive hot rolled silicon steel for the remainder of the magnetic circuit.

A magnetic core design yielding the highest efficiency with the preferred crystal orientation steel is desirable.

It is a purpose of this invention to provide an improved construction involving the use of a novel lamination bonding composition.

Referring to the figures of the drawing, Fig. 1 shows a shell type transformer comprising a stack of laminations 16 about which the primary coil 26 and the secondary coil 28 are wound. Abutting the upper and lower ends of the stack 16 are transverse stacks of laminations 12, 14, 18 and 20 continuing the magnetic flux path. The external ends of the stacks 12 and 14 are connected by a stack of laminations 24 while the corresponding ends of the stacks 20 and 18 are connected by the stack of laminations 22.

It will be readily seen that it will be economical to make the center leg or stack of laminations 16 of the smallest possible cross-section capable of carrying the rated magnetic flux. By using silicon steel having the preferred grain orientation the center leg may be worked at a higher flux density than the other legs of the transformer and less copper will be necessary. It is

accordingly advantageous to employ for the center stack 16 laminations made of Hipersil or some other highly efficient magnetic material. The stacks 12, 14, 18, 20, 24 and 22 may be made of sheets of ordinary hot rolled magnetic steel with satisfactory results. Thus without constructing the entire transformer core of the more expensive magnetic material, a satisfactory construction with a more economical arrangement of materials has been obtained.

It has been found that the condition of the faces between the several stacks of laminations may introduce considerable loss into the operation of the apparatus. For example, the laminations are commonly stamped or cut from large sheets of material. These operations introduce burrs which may contact adjacent sheets and connect the two electrically, whereby eddy currents may flow from one to the other and cause large core losses.

Furthermore, the irregular surfaces created at the cut or punched portions of the sheet do not provide for close joints between stacks of laminations. A large air gap between stacks is a source of energy loss. It is accordingly proposed to eliminate the burrs and create close joints between contiguous stacks of laminations by first grinding the assembled stacks at the surfaces, which will contact, and thereafter etching the ground face with a chemical reagent which will eat away any fine burrs and other projections.

Coinciding with the treatment of the joints, it has been long recognized that laminations carrying a magnetic flux must be electrically insulated from each other in order to decrease eddy currents. The thickness of the insulating medium or substance between laminations determines the electrical resistivity to eddy current losses. On the other hand, a great amount of insulating medium between laminations increases the physical dimensions for a stack of laminations having a given amount of magnetic material. Consequently the size may increase to a point where the benefit of the added insulation is more than overcome by the increased physical and cost considerations.

It is a purpose of the invention to employ a heat treated resinous adhesive composition to bond laminations into stacks suitable for cores in electrical equipment, the composition having good electrical insulating qualities in thin layers. Other demands upon the bonding composition which are met, are that it is both tough and elastic in order that the stresses encountered on heating and cooling and in ordinary assembling shall not cause delamination. Another desirable property present in such a bonding composition is adhesion to the magnetic material. Due to the grinding and etching operations at the joints between various stacks of laminations, the bonding composition also will prevent the penetration of water and acid in order that only the end faces of the sheet material be etched and not the flat faces.

A resin comprising polyvinyl acetal, which is the reaction product of 70% hydrolyzed vinyl acetate and acetaldehyde, and which has a 7 second viscosity for a 20% solution by the nitro-cellulose test method, has been found to be a satisfactory base for the bonding composition. This resin has a long chain molecule structure which gives good adhesive properties. For high temperatures in the electrical machinery, for example, in a range of 90° C. to 120° C., this resin may be used alone for bonding laminations.

Corresponding acetal resins may be used as a bonding composition. The reaction products between partially hydrolyzed vinyl esters such as the acetates, propionates or butyrates or mixtures thereof and an aldehyde, such as formaldehyde, propionaldehyde and butaldehyde, may, in some instances, be used in a similar manner for bonding laminations. The particular resin chosen will depend on the requirements to be met, such as oil resistance, softening point and bonding strength.

The polyvinyl acetal resin is dissolved in a solvent, for example, composed of 70% toluene or xylene and 30% ethyl alcohol. A solution containing 25% to 40% solids is suitable for application to the laminations.

In some instances the bonding composition may be modified by adding to the polyvinyl acetal resin up to 20% of a phenol aldehyde heat hardening resin. A cresylic acid-formaldehyde resin has been used with success, in the temperature range of 100° C. to 130° C. The phenol aldehyde type resin in the B stage is added to the polyvinyl acetal in solution. A solution as prepared above may be applied to the laminations for bonding purposes.

The phenol aldehyde resinous condensate addition may be modified with tung oil or oiticica oil up to 50% thereof and introduced into the composition containing polyvinyl acetal for use at operating temperatures below 125° C.

Where the electrical equipment is to be employed at the temperatures below 125° C., the bonding composition may be modified to provide for a greater plasticity than obtained by the above compositions. Polyvinyl acetate resin of an intermediate molecular weight, such, for example, as is sold on the market under the trade name of Vinylite (Ayat) has been found to give a satisfactory plasticizing effect in quantities of up to 80% of the total resins.

A specific composition containing the above ingredients which has been found satisfactory for bonding the transformer cores shown in Fig. 1 of the drawing had the following proportions:

	Per cent
Polyvinyl acetal	42½
Polyvinyl acetate	42½
The resinous condensate of cresylic acid and formaldehyde	15

The above composition is dissolved in a solvent composed of approximately two parts of toluene or xylene and one part ethyl alcohol to form a 25% to 40% solution. In some cases coal tar naphtha may be used in place of toluene or xylene.

This composition has produced bonds with strengths of 750 pounds per square inch to 1290 pounds per square inch between laminations. It has shown resistance to the chemical action of acids, dilute alkalis, water when used in subsequent processing and to the oils or insulating compositions employed in transformers. The bonding composition will not flow at temperatures of 100° C. under operating conditions. Thus a stable transformer core construction has been effected.

Another composition that has been employed with satisfactory results consists of a solution containing 20% to 40% solids consisting of 60% to 90% of partially hydrolyzed polyvinyl acetate, and 40% to 10% of phenol aldehyde type resin in the B stage. This particular mixture of resins has very good resistance to oil and good resist-

ance to the solvent action of halogenated liquid dielectrics.

The method of applying the solution to laminations to create satisfactory stacks of laminations which may be thereafter ground, etched and assembled into a highly efficient transformer core construction is as follows: The solution is applied as a varnish to punchings or laminations by spraying, brushing, or roll coating. It may be applied either as a coating of uniform thickness over the entire surface of each lamination or it may be applied in areas having different thickness, whereby upon subsequent heat treatment the composition will show an increased electrical insulating value between laminations. The subsequent treatment, however, is not altered regardless of the form of coating applied.

The coated laminations are flashed at a high temperature for a short time in order to remove the solvent from the composition. Suitable temperatures and times for this flashing are 450° C. for 20 seconds, 350° C. for 40 to 70 seconds and 250° C. for 125 to 150 seconds. Temperatures below 250° C. do not give as good results as treatment within the above range of temperatures.

After the flashing treatment the laminations are stacked into cores of predetermined size. Weighing may be employed to insure that the proper amount of magnetic material has been put into the core. The stack is placed within a clamping jig having adjustable portions whereby the stack may be consolidated under pressure to any selected thickness. However, the clamps at this stage are merely applied with a light pressure.

The stack of laminations in the clamping jig is heat treated at 200° C. to 260° C. for 5 hours for a stack of the size of 4 inches by 6 inches by 12 inches. During this time the resins react, particularly the phenol aldehyde resin which heat hardens.

At the end of the heat treating period, the stack of laminations with the clamps is removed from the ovens and the clamps are immediately adjusted to reduce the stack to the predetermined core size. The stack is allowed to cool in the clamps so adjusted to room temperature.

The stack of laminations after cooling may be ground and etched in order to create smooth plane faces providing for accurate contact with other stacks of laminations. This operation also removes the burrs. The plurality of stacks of laminations may be then assembled into the transformer 10 of Fig. 1 to give a transformer core construction which is economical in cost and efficient in operation.

A modified construction of transformer core is disclosed in Fig. 2. The construction of Fig. 2 employs for the entire core laminations of specially processed magnetic material, such as the Hipersil above mentioned. Due to the construction of Fig. 2 having the same cross section throughout the transformer core, the specially processed silicon steel may be used throughout.

The construction of Fig. 2 is further electrically efficient in that the path of the magnetic flux is so arranged that there are no substantial discontinuities or variations in the type of magnetic material it passes through. There are only two joints 46—46 or 44—44 in each core unit.

The transformer 30 comprises two continuous wound cores severed into similar portions 32, 38 and 34, 36. The continuous cores are formed by winding a continuous strip of magnetic material upon suitable forms until the desirable number

of laminations have been wound. The ends of the strips of steel are welded to the lamination immediately below.

The whole core is subjected to annealing to relieve internal strains due to winding.

In order to assemble the primary coil 40 and the secondary coil 42 about the central leg of the transformer 30, it is most convenient to sever the wound cores into the parts 34, 32 and 36, 38. This severing operation is facilitated by filling the spaces between laminations with the bonding composition of the type disclosed hereinbefore.

The bonding composition solution may be applied by vacuum impregnating the annealed core in a tank. The coil is introduced into a tank, the tank is closed and vacuum applied to remove all the air. The bonding composition solution is run in from a storage receptacle until the cores or laminations are covered. Then evacuation is discontinued and nitrogen gas is introduced and applied to the surface of the composition at atmospheric pressure in order to force the composition into the spaces between laminations. The laminations are allowed to soak for one-half hour in order to impregnate them with the maximum amount of composition. Pressure can be applied to speed up the impregnation. The composition is thereafter removed from the tank and the core is taken out.

In order to prevent the innermost laminations from warping during subsequent treatment, it is desirable to place blocks, or springs, or other spacing means within the window or open space within each continuous core.

Thereafter, the impregnated coil is baked in ovens within a temperature range of 200 to 260° C. for four hours for a 35 pound core. The composition bonds the laminations well enough so that the cores may be readily cut at the places indicated at 44 and 46 in the drawing without the laminations breaking apart. Oil is used as a lubricant in the cutting operation due to the fact that the above process does not give a 100% filling. The oil retards entrance of water, acid, etc., used in subsequent processing.

The joints are then ground and etched as indicated in the discussion with respect to Fig. 1. In this manner, perfectly flat and substantially smooth plane surfaces are obtained at joints 46—46 and 44—44 so that the magnetic flux has a minimum air gap loss.

The composition possesses excellent insulating properties at space factors of 97% to 85% with low eddy current loss between the laminations.

In some instances it has been found that the metal laminations can be treated with certain chemicals to cause an insulating film to form directly on the surface of the sheet metal. In this way a double insulating effect is obtained. The film of insulating material formed by such treatment on the surface of the sheet material is an adherent scale, for example, a magnesium silicate ($MgO-SiO_2$). Brittle resins, for example, an all phenol-aldehyde type resin would give an exceedingly brittle and hard bonding composition which would tend to disrupt the scale from the surface of the sheet metal under normal operating stresses and reduce the benefit of such treatment. The bonding composition hereinabove disclosed is sufficiently plastic to avoid disruption of this insulating scale.

Since certain changes may be made in the above article and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matters

contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim as my invention:

1. A bonded core comprising laminations of magnetic material bonded by a heat-treated insulating composition between laminations, the bonding composition being composed of from 20% to 80% of polyvinyl acetal, from 0 to 80% of polyvinyl acetate for plasticizing the composition and from significant amounts up to 20% of a heat hardening phenol aldehyde type resinous condensate to provide for a thermosetting agent during heat-treatment to effect consolidation of the laminations.

2. A bonded transformer core comprising laminations of magnetic material and a heat treated insulating composition between laminations to effect consolidation of the laminations, the composition including about 42.5% of polyvinyl acetal, about 42.5% polyvinyl acetate and about 15% of cresylic acid and formaldehyde resinous condensate.

3. In a core structure, comprising in combination, a continuous laminated wound core of a silicon magnetic steel with the direction of the easiest magnetization of the grains oriented in the direction of the winding, the core being an-

nealed after being wound to relieve internal strains, and a heat-treated electrically insulating bonding composition between laminations, the composition comprising polyvinyl acetal, polyvinyl acetate and a heat hardening phenol aldehyde type resinous condensate, the composition having long chain molecules to provide for toughness and elasticity and being characterized by resistance to the chemical and physical action of acids, dilute alkali, water and oil.

4. In a core structure comprising in combination, a continuous laminated core of a high silicon magnetic steel with the direction of the easiest magnetization of the grains oriented in the direction of the winding, the core being annealed after being wound to relieve internal strains, and a heat-treated electrically insulating bonding composition between laminations, the composition being composed of about 42.5% polyvinyl acetate, about 42.5% polyvinyl acetal and about 15% of cresylic acid-formaldehyde condensate, the composition having long chain molecules to provide for toughness and elasticity and being characterized by resistance to the chemical and physical action of acids, dilute alkali, water and oil.

JAMES G. FORD.