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(54) METHOD OF BONDING LAMINATED ASSEMBLIES

(71) We, GEO. L. SCOTT & CO, LIMITED, of Cromwell Road, Ellesmere Port, Merseyside L65 4DT; a British company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of bonding an assembly and, more particularly, relates to a method of bonding a laminated assembly such as a rotor or stator for an electric motor.

Claim 11 of our British Patent Specification No. 1,406,645 claims a method of bonding a laminated assembly, more particularly a rotor or stator for an electric motor comprising the steps of aligning the components to be bonded, impregnating the aligned components with a thermosetting resinous composition comprising an epoxy resin plus a hardener therefor, one or more polymerisable monomers, a cross linking agent and a free radical polymerisation initiator in the form of an azo-compound by capillary action and at least partially curing the impregnated assembly. However, it has now been found that various modifications can be made to the above method, which modifications make the process cheaper and easier to operate.

At the time of filing British Patent Specification No. 1,406,645 it was virtually unknown, in practice, to bond together laminations intended to form a rotor or a stator for an electric motor. A method of bonding laminations together was, at that time, known but was extremely complex and could not be performed by unskilled personnel. Such method required the rotor or stator to be fully assembled, and heated for a period of several hours at a temperature in excess of 100°C. Thereafter, the electrical component was placed inside a pressure-tight vessel which was evacuated to a high vacuum. The components was then immersed in an epoxy resin whilst maintaining the vacuum and the surface of the epoxy resin was subjected to a pressure above

atmospheric pressure. The epoxy resin is then stated to impregnate the electrical component and to fill all voids and interstices therein.

This prior art system cannot be regarded as impregnation by capillary action. Accordingly, attempts were made to provide a simpler method for bonding laminations together. Accordingly we devised a composition set forth in claim 1 of British Patent Specification No. 1,406,645. At that time, it was believed that this composition was the only composition which could be utilised for carrying out the method set forth in claim 11 of that specification.

In the introduction to British Patent Specification No. 1,406,645, attention was drawn to the problems involved in the use of solvent-based resin systems as bonding agents and to the reasons why they could not be used for bonding together laminations. Moreover, it was also stated that a cyano-acrylate resin was known for bonding rotors or stators. However, only the outer surfaces of a completed electrical component were provided with a coating of such a resin, which coating merely made the external surface of the component impervious to water.

It has now been found that other bonding systems than that disclosed in British Patent Specification 1,406,645 can be employed to bond laminations.

According to the present invention there is provided for bonding a laminated assembly by impregnation with a bonding agent wherein aligned laminations which abut one another are impregnated with a bonding agent in solution or in a suspension, the bonding agent comprising an epoxy resin, and a hardener for the epoxy resin, which hardener exhibits polar properties, the solvent or mixture of solvents utilised to form the solution or suspension exhibiting both polar and non-polar properties, the solution or suspension having a viscosity and surface tension such as to permeate between abutting laminations solely by capillary action, and the solvent being removed in such a

manner as to cause the bonding agent to bond the laminations together.

In its broadest aspect, therefore, the present invention covers a method of bonding in which the laminations are bonded together. However, the bonding agent must be cured. This can, in most circumstances, be effected by merely allowing the bonded component to stand for a period of time. However, self-curing of epoxy resins is comparatively slow. Thus, an electrical component weighing, say, 400 g may take as long as a week to cure at room temperature.

Accordingly, it is highly desirable to cure the bonding agent by heating, preferably either by resistance or induction heating. We have found that certain solvent-based bonding agents of the above type are capable of resisting relatively high temperatures without causing problems of bubbling when the solvent evaporates.

In bonding systems of this type, the solvent preferably has a relatively low vapour pressure. In one particularly advantageous embodiment of the present invention the solvent employed is selected from organic solvents such as cyclohexanone, styrene, benzene, toluene or xylenes, or monoalkyl ethers or acyl salts of such ethers or mixtures of such solvents subject to the proviso that the solvent or mixture of solvents exhibits some degree of both polar and non-polar properties. The hardener for the epoxy resin may be of any suitable type but is preferably a substituted or unsubstituted guanidine, especially dicyanodiamide. Alternatively, the hardener may be an unsubstituted or substituted dihydrazide. The hardener is advantageously employed in the form of particles having a diameter of 10^{-5} to 10^{-7} metres. The above-specified hardeners all have one or more amino-groups and all combine, in use with the epoxy groups of the epoxy resin. As will readily be appreciated, some hardeners have a plurality of amino groups, each of which may react with an epoxy group. However, it is unlikely that all such amino groups will react with epoxy groups due to steric effects. Basically, the hardener must have a group located thereon reactable with the epoxy resin and, if substituents are present in the hardener, these substituents desirably form electron inductive groups which are capable of reducing the electron density in the groups reactable with the epoxy resin. Thus in dicyanodiamide, the cyano groups are strongly electrophilic and cause activation of the amino groups. Alternatively, the hardener may be n-butyroguanidine in which case the butyro-group is weakly electrophilic and has a similar effect to the cyano groups of the dicyanodiamide.

In a further preferable embodiment of the present invention, the laminations to be

bonded are supported during the impregnation and curing stages, the support means thereafter being removed.

The impregnation of the supported laminations may be effected by spraying the solution or suspension on to the internal or external periphery of the laminations to be bonded. Alternatively, the supported laminations may be rolled over a pad impregnated with the solution or suspension of the bonding agent or by a conventional liquid transfer method. By so doing, the solution or suspension of the bonding agent will be conveyed to all interlaminar parts of the assembly to be bonded together.

The invention will be further described with reference to two embodiments thereof. In the first embodiment, a plurality of laminations are to be bonded together to form a rotor for an electric motor. Each individual lamination comprises a central core region having a plurality of radially extending arms provided around its outer periphery. Each of these radially extending arms terminates in a substantially T-shaped head portion. The inner periphery of the central core defines a central aperture. The number of laminations to be bonded together is determined by the size of the finished rotor. The desired number of laminations are extracted from a stack of laminations by utilising suitable means such as a selector which is desired to collect the appropriate number of laminations. The laminations are then located on a block having at least three aligning pins located thereon. When located on the block, the outer periphery of the central core of each lamination lies relatively close to each of the three pins, each pin lying between two adjacent radial arms of each lamination. The thus aligned laminations are then compressed by utilising, for example, a hydraulic ram so to ensure that adjacent laminations abut one another. A mandrel, which is in interference fit, is then passed through the aligned central apertures of the laminations, the mandrel acting as a supporting member.

The thus aligned and supported laminations are then transferred to a wicking station. The wicking station comprises, in this embodiment, a pad impregnated with a solution or suspension of a suitable bonding agent. In the present embodiment, the bonding agent comprises an epoxy resin and a hardener therefor, the hardener being a triethylenetetramine. The ratio of the components is 10 parts by weight resin to one part by weight hardener. The bonding agent is dissolved in cyclohexanone. The triethylenetetramine hardener is utilised in the form of a liquid.

In the bonding agent itself, the epoxy resin appears to be in solution in the hardener. However, such a solution has a

high viscosity and surface tension. When the cyclohexanone is added to the bonding agent, both the epoxy resin and the hardener dissolve in the cyclohexanone. The ratio of resin/hardener to solvent is 40% of the former to 60% of the latter (by volume). By dissolving the epoxy resin and the hardener in the solvent, which effectively acts as a diluent, two major advantages accrue. Firstly, the solution is much easier to handle than a highly viscous epoxy resin. Secondly, by using a solution, the epoxy resin can be caused to wick between the laminations by capillary action. It will no doubt be recalled that the laminations to be bonded are stated to be in abutment with one another. However, due to the practical impossibility of processing the laminations to ensure that they are perfectly flat, the abutment between adjacent laminations will take place only at isolated points. Due to the low surface tension and viscosity of the solution, the epoxy resin and hardener will be carried, by the solvent, from the external periphery of the laminations to adjacent central apertures thereof. In this respect, the amount of bonding agent supplied to the external periphery of the laminations should be so selected that the epoxy resin is only transported in a sufficient quantity so as to just reach the mandrel.

This gives maximum bonding, fills all inter-laminar spaces with the epoxy resin, but does not cause the laminations to become bonded to the mandrel.

It has been stated that the epoxy resin and hardener may be dissolved in any solvent, or mixtures of solvents, with which they are compatible. In this respect, it is pointed out that one particularly useful solvent is cyclohexanone. On the other hand, aliphatic alcohols and straight or branched chain aliphatic hydrocarbons are not compatible with most, if not all, epoxy resins and therefore are of limited use. A typical rotor formed of laminations bonded together in this manner weighs approximately 400 g but is still not ready for use since the epoxy resin must be cured. This is effected by leaving the bonded laminations at room temperature for one week. The mandrel is then removed.

In the second embodiment, a similar method is employed. However, in this embodiment, the hardener is dicyanodiamide and the solvent is a mixture of xylene and 2-ethoxy ethanol in a 1:1 ratio by volume. The dicyanodiamide is employed in the form of extremely finely ground solid particles having a diameter of the order of 10^{-5} to 10^{-7} metres. In the bonding agent itself the dicyanodiamide appears to be in suspension in the epoxy resin. However, when the solvent is added, both the epoxy resin and the hardener dissolve therein. The ratio

of epoxy resin/hardener to the solvent is 40% : 60% (by volume). The same advantages accrue as in the first embodiment.

However, the curing of the epoxy resin is effected differently. In this case, the thus impregnated laminations, still supported on the mandrel, are then transferred to a curing oven wherein they are heat cured. This heat curing has two purposes. Firstly, the solvent is removed, and secondly, the dicyanodiamide hardener causes the epoxy resin to become cross-linked. To ensure that such cross-linking takes place rapidly, the curing temperature must not be below 210°C and we utilise a temperature of 280° — 290°C . It is also pointed out that, within reason, curing and therefore cross-linking is improved with higher temperature. The length of time that the impregnated laminations remain in the curing oven is dependent upon the curing temperature, the number of laminations that have to be bonded together and the material from which the laminations are made. Thus, for a rotor weighing approximately 400 g, the heat curing is effected at 280° — 290°C for 12 minutes. When the assembly of laminations has been sufficiently cured, the support mandrel is then removed.

Various minor modifications can be made to the present invention without departing from the scope thereof. Thus, in the specific embodiment described above, a single epoxy resin is used. However, mixtures of linear, polymeric epoxy resins may be employed, if desired. Similarly, a mixture of one or more epoxy resins with one or more phenolic, urethane or nitrile resins may also be employed. It should, however, be noted that, in each case a hardener for the at least one epoxy resin and a suitable solvent for the hardener and epoxy resin or epoxy resin containing mixture must be provided.

These modifications provide certain advantages. Thus, whilst it is desirable to cure the impregnated laminations in a curing oven, this is by no means essential. If time permits, the impregnated assembly may be cured at a lower temperature. It is, of course, essential that the impregnated assembly is cured at a temperature at or above that at which the hardener causes the epoxy resin to become cross-linked. Thus, a guanidine derivative hardener will not cure at ambient temperature. However, other types of hardener will self-cure at room temperature, given sufficient time. This self-curing aspect is of particular importance if the assembly is relatively large and no suitable curing oven is available.

The alignment means can be located in any suitable position relative to the laminations. Similarly, the supported laminations may be impregnated by methods other than rolling over an impregnated pad. Thus,

for example, the impregnation can be effected by spraying. Effecting the impregnation by spraying has distinct advantages if a plurality of laminations are to be bonded together to form a stator. It will be readily appreciated that the external configuration of a stator is often rectangular. Accordingly, it is difficult to roll a work-piece having a square or rectangular external cross-section across an impregnated pad. To impregnate the laminations which form the stator, the aligned and supported laminations pass through a spraying station which comprises one or more nozzles so arranged as to be capable of directing a bonding agent onto the external periphery of the laminations. If desired, a spraying technique can also be employed to impregnate laminations to be bonded together to form a rotor.

WHAT WE CLAIM IS:—

1. A process for bonding a laminated assembly by impregnation with a bonding agent wherein aligned laminations which abut one another are impregnated with a bonding agent in solution or a suspension, the bonding agent comprising an epoxy resin and a hardener for the epoxy resin, which hardener exhibits polar properties, the solvent or mixture of solvents utilised to form the solution or suspension exhibiting both polar and non-polar properties, the solution or suspension having a viscosity and surface tension such as to permeate between abutting laminations solely by capillary action, and the solvent being removed in such a manner as to cause the bonding agent to bond the laminations together.
2. A process as claimed in claim 1 wherein the impregnated assembly is heat-cured.
3. A process as claimed in claim 2 wherein the curing is effected by resistance heating.
4. A process as claimed in claim 2 wherein the curing is effected by induction heating.
5. A process as claimed in any one of claims 1 to 4 wherein the solvent is an organic solvent selected from cyclohexanone, styrene, benzene, toluene, xylenes, monoalkyl ethers or acyl-substituted monoalkyl ethers, or mixtures of such solvents.
6. A process as claimed in any preceding claim wherein the hardener includes an electrophilic group.

7. A process as claimed in claim 6 wherein the solvent is cyclohexanone and the hardener is triethylenetetramine.

8. A process as claimed in claim 5 or 6 wherein the solvent is other than cyclohexanone and the hardener is a substituted or unsubstituted guanidine.

9. A process as claimed in claim 5 or 6 wherein the solvent is other than cyclohexanone and the hardener is a substituted or unsubstituted dihydrazide.

10. A process as claimed in claim 8 or 9 wherein the hardener is a substituted guanidine or dihydrazide, the or at least one substituent being an electron inductive group.

11. A process as claimed in claim 8 wherein the hardener is n-butyroguanidine.

12. A process as claimed in any one of claims 8 to 11 wherein the hardener is employed in particulate form, the particles having an average diameter of 10^{-5} to 10^{-7} m.

13. A process as claimed in any one of claims 1 to 6 or 8 to 12 wherein the laminations to be bonded are supported during the impregnation and curing stages, the support means thereafter being removed.

14. A process as claimed in any preceding claim wherein the impregnation of the supported laminations with the solution or suspension of the bonding agent is effected by spraying.

15. A process as claimed in any one of claims 1 to 13 wherein the impregnation of the supported laminations with the solution or suspension of the bonding agent is effected by rolling the supported laminations over a pad impregnated with the solution or suspension.

16. A process for bonding a laminated assembly as claimed in claim 1 substantially as hereinbefore described.

17. A laminated assembly when bonded by a process as claimed in any one of claims 1 to 16.

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