

DESCRIPTION

BONDING-USE SURFACE-COATED ELECTRICAL STEEL SHEET

5 TECHNICAL FIELD

The present invention relates to a surface-coated electrical steel sheet for bonding by heating and/or pressing after punching or shearing.

BACKGROUND ART

10 In general, when using electrical steel sheet for putting together a stacked core of a motor, transformer, etc., it is sheared or punched to obtain core units which are then stacked and fastened together by bolting, calking, welding, bonding, etc. After this, the core is
15 sent to the next process such as assembly of the winding coil.

As the method of fastening a stacked core, there is the method of coating the surface of the steel sheet by an insulation film called an "adhesive coating"
20 exhibiting adhesiveness under heating and/or pressing, punching the sheet into core units, stacking them, then pressing and heating them to obtain the fastened core, whereby a stacked core free of thermal strain and mechanical strain and superior in rigidity is obtained.

25 The adhesive coating has to act as an adhesive for fastening the core and to act as an insulating coating formed on the surface of the electrical steel sheet, but the properties considered necessary for an adhesive and the properties considered necessary for an insulating
30 coating often are contradictory and therefore sophisticated technology is sought. For example, as a property of an adhesive, softness is considered good in order to easily achieve a uniform bonding state, while for an insulating coating, a hard coating is better so
35 that the surface is not scratched when punching the sheet into core units. Further, an adhesive should have a high wettability of the surface to be coated so as to enable

strong adhesiveness of core units, but an insulating coating should have a low wettability for maintaining the corrosion resistance.

5 To satisfy these contradictory required properties, Japanese Unexamined Patent Publication (Kokai) No. 6-182296 proposes the technology of uniformly coating the surface of steel sheet with a mixed solution mainly comprised of an acrylic modified epoxy resin emulsion containing a latent curing agent and then baking it to an
10 incomplete state. The stability of the treatment solution is good, the coating efficiency is good, and a bonding use surface-coated steel sheet with a good ability to be stored a long time is obtained.

15 In the technology described in Japanese Unexamined Patent Publication (Kokai) No. 6-182296, however, there was the problem that when stacking core units and heating and pressing them for fastening, it was difficult to bond the entire surfaces of the core units. That is, the latent curing agent included in advance chemically
20 reacted with the epoxy resin due to the heating to cure the coatings for bonding, but the heating caused the adhesive coatings on the surfaces of the core units to intermix and fuse and simultaneously the epoxy resin and epoxy curing agent to react for curing, so sometimes the
25 curing reaction proceeded partially in advance and the entire surfaces of the steel sheets were not bonded. Since the entire surfaces of the steel sheets were not bonded and variations occurred in the bond strength of the steel sheets in the partially fastened state and
30 consequently parts with weak bond strengths occurred, there was the problem that the core would fall apart during production or would become a cause of abnormal vibration during rotation in a motor etc.

35 Therefore, Japanese Unexamined Patent Publication (Kokai) No. 10-343276 discloses the technology of mixing an epoxy resin curing agent into a resin composition obtained by esterification of an acrylic-based resin and

epoxy resin and making the peak temperature of the logarithmic subtraction rate of the resin composition 80 to 200°C. This technology makes full surface bonding possible in that the adhesive coatings of the steel sheet surfaces melt and intermix, then a curing reaction of the resin composition proceeds.

In recent years, along with the rise in interest over global environmental issues, higher efficiency has been strongly sought from motors and transformers. To improve the efficiency of motors and transformers, an improvement of the space factor has been sought for electrical steel sheet as well. Reduction of the thickness of adhesive coatings to less than 3 μm is being demanded. However, with the technology described in Japanese Unexamined Patent Publication (Kokai) No. 10-343376, it was learned that the problem of the difficulty in bonding the entire surfaces of the core units remained when making the adhesive coatings thinner.

That is, in general, electrical steel sheet coated with an adhesive coating is usually coated thickly to a thickness of 3 to 8 μm compared with the thickness of about 1 to 2 μm of an inorganic/organic mixed insulating coating coated on nonoriented electrical steel sheet. The reason is that if the thickness is smaller, there will be parts not contacting at the surface even with fine surface relief such as with rolling defects caused when rolling the steel sheet and therefore there will be parts not bonded with the parts to be bonded with.

The surface roughness of steel sheet, while naturally depending on the settings of the rolling mill, is about 1 to 5 μm in terms of the difference (R_{max}) between the highest point and lowest point in a predetermined measurement range. Therefore, a coating thickness of at least this difference is required. A remarkable phenomenon occurring when the thickness is small is that while a relatively high bond strength is

secured when measuring the bond strength using single sheets, the strength in the direction pushing apart the stacked side surface when making a stacked core falls. As a result, even if not a problematic level in tests of the bond strength using single sheets, the problem will arise that clearance will occur at the stacked side surface when making a stacked core and in the worst case the stacked core will fall apart due to shock during handling.

Further, when coating an adhesive coating with heat resistance on an electrical steel sheet given an ordinary organic/inorganic mixed insulation coating or inorganic insulating coating, it was learned that the problem would sometimes also arise of peeling occurring between the ordinary insulating coating and the electrical steel sheet and the bond strength falling.

As technology for reducing the internal stress of an epoxy resin, various methods have been disclosed and suggested up until now. For example, Japanese Unexamined Patent Publication (Kokai) No. 62-50361 discloses technology for using an epoxy resin composition characterized by including particulate of a polymer with a glass transition temperature not reaching room temperature present in the system. With this adhesive coating, heat resistance with respect to a rise in temperature due to generation of Joule's heat is required since the sheet is used as a core for a motor or transformer. The invention described in this publication enables the heat resistance to be held and further the internal stress to be reduced.

However, the technology disclosed in Japanese Unexamined Patent Publication (Kokai) No. 62-50361 is technology extremely useful in terms of the effect of reducing the internal stress in an epoxy resin, but does not envision an adhesive coating requiring properties of both an adhesive and the insulating coating of an electrical steel sheet and is not technology satisfying

the properties of corrosion resistance and blocking required by an adhesive coating, so has many problems as an adhesive coating.

DISCLOSURE OF INVENTION

5 The inventors engaged in various experiments and discovered that this problem occurs due to coating an adhesive coating in case of thin coating thickness and that the so-called "internal stress" is large and
10 discovered that it could be solved by reducing the internal stress of the adhesive coating.

 The inventors found a discovery for reducing the internal stress of an adhesive coating, discovered an adhesive coating improving the bond strength in the direction pushing apart the bonded surfaces of adhesive
15 coatings in the case of a thin film or able to prevent a drop in the bond strength when forming a usual insulating coating and then forming an adhesive coating on it and thereby completed the present invention.

 That is, the present invention has as its gist the
20 following:

 (1) An electrical steel sheet having on its surface an insulating coating exhibiting bondability by heating and/or pressing, said bonding use surface-coated electrical steel sheet characterized in that said coating
25 comprises a mixture of an epoxy resin or modified epoxy resin having a glass transition temperature (T_g) of 80°C to 150°C and an epoxy resin curing agent and particulate polymer having a particle size of 0.01 to $0.5\ \mu\text{m}$.

 (2) A bonding use surface-coated electrical steel
30 sheet as set forth in (1), characterized in that the T_g of said particulate polymer is 10°C to 80°C .

 (3) A bonding use surface-coated electrical steel sheet as set forth in (1), characterized in that said particulate polymer is an acrylic-based resin.

35 (4) A bonding use surface-coated electric steel sheet as set forth in (1), characterized by containing 1 to 30 parts by weight of the particulate polymer with

respect to 100 parts by weight of the epoxy resin.

(5) A bonding use surface-coated electrical steel sheet as set forth in (1), characterized in that said epoxy resin is modified by an esterification reaction
5 with an acrylic-based resin in advance.

(6) A bonding use surface-coated electrical steel sheet as set forth in any one of (1) to (5), characterized in that an electrical steel sheet formed on its surface with an organic/inorganic mixed insulating
10 coating or an inorganic insulating coating is formed with an insulating coating having bondability comprised of an epoxy resin or modified epoxy resin and an epoxy resin curing agent and particulate polymer dispersed therein.

BRIEF DESCRIPTION OF DRAWINGS

15 FIG. 1 gives views of the surface conditions, observed under a scanning electron microscope, of bonded surfaces obtained by bonding sample sheets according to the present invention (Fig. 1B) and prior art (Fig. 1A) punched into 2 cm x 3 cm shapes by heating and/or
20 pressing at $200^{\circ}\text{C} \times 10 \text{ kgf/cm}^2 \times 30 \text{ minutes}$, then performing push apart tests at ordinary temperature and then finally recovering and breaking apart the samples.

FIG. 2 gives a conceptual view of a peeling test method used as one of the methods for measurement of bond
25 strength and a conceptual view of a push apart test method newly devised for working the present invention. Each is a method of measurement of the peeling strength which peels apart steel sheets bonded by an adhesive coating, but with the peeling test method, the steel
30 sheet greatly deforms, so the effects of the properties of the steel sheet itself are extremely large, while with the push apart test method, the plurality of steel sheets are stacked and fastened so the effects of the steel sheets are kept to a minimum and the properties of the
35 bonding members can be closely evaluated.

BEST MODE FOR CARRYING OUT THE INVENTION

Below, specific embodiments for working the present

invention will be explained.

With the coating of the present invention, it is necessary that the epoxy resin or the modified epoxy resin have the epoxy resin curing agent and specific
5 organic resin particles of a particle size in the range of 0.01 to 0.5 μm dispersed in it.

The epoxy resin used in the present invention is not particularly limited so long as it is one having a glass transition point (T_g) after curing of 80°C to 150°C, is
10 liquid, preferably solid, at ordinary temperature before the curing reaction, and has at least one epoxy group on an average in the monomer, but it preferably has an epoxy equivalent of 100 to 5000.

Specifically, there is a bisphenol A, F, and AD
15 type, phenolic novolak type, ortho-cresol novolak type, phenol-based compound modified type, etc. One having an aromatic ring structure in the monomer is preferred.

In the coating of the present invention, it is possible to use not only an epoxy resin, but also a
20 modified epoxy resin. The method of modifying the epoxy resin is not particularly limited, but it is possible to use a specific substituent group in the main chain or bonding various compounds with the epoxy group at the epoxy resin terminal or hydroxyl group at the side chain.
25 In particular, the adhesive coating is preferably one where the curing reaction of the epoxy resin will proceed after the resin components melt, so as the modified form, an acrylic modified epoxy resin comprised of an epoxy resin modified by an acrylic-based resin in an
30 esterification reaction is preferable.

As the acrylic-based resin used for the above modified epoxy resin, a polymer of a polymeric monomer including a carboxyl group containing vinyl polymer is
35 suitable. Specifically, it is comprised at least one monomer selected from alkyl esters, hydroxyalkyl esters, and N-hydroxyalkylamides of an α,β -ethylenic unsaturated

carboxylic acid, an α,β -ethylenic unsaturated monomer having a carboxylic group, and a styrene-based vinyl monomer and can be obtained by causing copolymerization of a mixture of these in an organic solvent using an
5 ordinary radical polymerization initiator.

As the alkyl ester of an α,β -ethylenic unsaturated carboxylic acid used in the present invention, for example, there are acrylic acid esters (methyl acrylate, ethyl acrylate, isopropyl acrylate, isobutyl acrylate, n-
10 butyl acrylate, n-amyl acrylate, n-hexyl acrylate, isooctyl acrylate, n-octyl acrylate, methoxyethyl acrylate, ethoxyethyl acrylate, 2-ethylbutyl acrylate, 2-ethylhexyl acrylate, decyl acrylate, etc.) and methacrylic acid esters (methyl methacrylate, ethyl
15 methacrylate, propyl methacrylate, isobutyl methacrylate, n-butyl methacrylate, n-amyl methacrylate, n-hexyl methacrylate, decyloctyl methacrylate, 2-ethylhexyl methacrylate, decyl methacrylate, etc.)

As the hydroxyalkyl ester of an α,β -ethylenic
20 unsaturated carboxylic acid, for example, there are N-methylol acrylamide, N-methylol methacrylamide, N-butoxymethyl acrylamide, N-butoxymethyl methacrylamide, and other N-substituted acrylic-based monomers.

In the present invention, it is preferable to
25 include at least one type of monomer selected from the above α,β -ethylenic unsaturated carboxylic acid monomers.

Next, as an α,β -ethylenic unsaturated carboxylic acid monomer having a carboxyl group, for example, acrylic acid, methacrylic acid, maleic acid, anhydrous
30 maleic acid, fumaric acid, crotonic acid, itaconic acid, citraconic acid, cinnamic acid, etc. may be mentioned.

As the styrene-based vinyl monomer, for example, styrene, vinyl toluene, t-butyl styrene, etc. may be mentioned.

35 In the production of the above carboxyl group

containing vinyl polymer, while not particularly limited to it, the α,β -ethylenic unsaturated monomer having the carboxyl group is preferably included in an amount of 10 to 60 wt% with respect to the total monomer, particularly preferably 15 to 30 wt%, and the copolymerization temperature is preferably 50 to 150°C, particularly preferably 60 to 90°C.

The reason for limiting the Tg of the epoxy resin or modified epoxy resin after curing to 80°C to 150°C is that, under 80°C, the heat resistance after bonding is inferior and the heat generated at the time of driving the motor or transformer cannot be withstood, while above 150°C, the coating becomes too hard and the bond strength falls or deterioration proceeds too much due to the vibration at the time of use as a motor or transformer. Particularly preferable is a range of 90 to 120°C, more preferable range is 110 - 120°C. This temperature range can reduce an internal stress of an adhesive coating because the particulate polymer disperses in an epoxy resin.

Next, as the particulate polymer used in the present invention, it is possible to use one having a particle size in the range of 0.01 μm to 0.5 μm and able to remain stably present in a dispersed state in an epoxy resin. As the type of the particulate polymer able to be used in the present invention, an acrylic resin, vinyl acetate, polyester, polyurethane, polyethylene, polypropylene, polycarbonate, etc. are suitable.

Specifically, as an acrylic resin, there are acrylic acid esters (methyl acrylate, ethyl acrylate, isopropyl acrylate, isobutyl acrylate, n-butyl acrylate, n-amyl acrylate, n-hexyl acrylate, isooctyl acrylate, n-octyl acrylate, methoxyethyl acrylate, ethoxyethyl acrylate, 2-ethylbutyl acrylate, 2-ethylhexyl acrylate, decyl acrylate, etc.), methacrylic acid esters (methyl methacrylate, ethyl methacrylate, propyl methacrylate,

isobutyl methacrylate, n-butyl methacrylate, n-amyl methacrylate, n-hexyl methacrylate, lauryl methacrylate, stearyl methacrylate, n-octyl methacrylate, decyloctyl methacrylate, 2-ethylhexyl methacrylate, decyl methacrylate, etc.), 2-hydroxyethyl acrylate, hydroxypropyl acrylate, 3-hydroxybutyl acrylate, 2,2-bis(hydroxymethyl)ethyl acrylate, 2-hydroxyethyl methacrylate, 3-hydroxybutyl methacrylate, hydroxypropyl methacrylate, 2,3-dihydroxypropyl methacrylate, N-methylol acrylamide, N-methylol methacrylamide, N-butoxymethyl acrylamide, N-butoxymethyl methacrylamide, acrylic acid, methacrylic acid, maleic acid, anhydrous maleic acid, fumaric acid, crotonic acid, itaconic acid, citraconic acid, cinnamic acid, styrene, vinyl toluene, t-butyl styrene, or another monomer emulsion polymerized by a one step or two or more step process.

As the vinyl acetate, there are vinyl acetate, a vinyl acetate-veova copolymer, vinyl acetate-ethylene copolymer, etc.

As the polyurethane, it is possible to use one having urethane bonds in the monomer and obtained from a chemical reaction between an isocyanate compound and polyol or polyether, for example, one synthesized from a tolylene diisocyanate, diphenylmethane-4,4-diisocyanate, hexamethylene diisocyanate, trimethylpropane-1-methyl-2-isocyano-4-carbamate, polymethylene polyphenylisocyanate, methaxylene diisocyanate, or other isocyanate compound and polyethylene glycol, polypropylene glycol, polyether triol, or other polyol or polyether.

As the polyester, it is possible to use a general one obtained by reacting a dibasic acid and bivalent alcohol. Specifically, as the dibasic acid, anhydrous maleic acid, fumaric acid, adipic acid, anhydrous phthalic acid, and isophthalic acid and, as the bivalent alcohol, ethylene glycol, propylene glycol, diethylene glycol, 1,3-butylene glycol, dipropylene glycol, neopentyl glycol, bisphenol dioxyethyl ether, etc. can be

used.

The particulate polymer used in the present invention has to have a particle size in the range of 0.01 μm to 0.5 μm . If the particle size is less than 0.01 μm , the effect of the present invention of the improvement of the bonding strength even when the coating is thin is not obtained, while if over 0.5 μm , the melting of the epoxy resins will be obstructed and the bonding strength will be lowered.

The inventors discovered that in the adhesive coating, the particle size at the time of dispersion has an important action and that by using a particulate polymer of a particle size of an extremely narrow range of 0.01 μm to 0.5 μm , it is possible to satisfy the properties required for the adhesive coating.

The reason for this is that since the coating film is extremely thin, that is, several μm or even at the thickest 10 or so μm , there are inherent limits to the size in order for the particulate to disperse uniformly in the epoxy resin. For example, if adding particulate of a particle size larger than the coating thickness, regions formed by only the particulate would appear at the time of coating and drying, whereby so-called "sea island structure" could not be formed and therefore the effect of the present invention could not be obtained. Accordingly, the particle size of the particulate polymer from which the effect of the invention can be obtained is limited to an extremely narrow range. The inventors studied this and as a result found that the range of more than 0.05 μm is particularly preferable. More preferable range is more than 0.1 μm , and the most preferable range is 0.2 - 0.4 μm .

The particulate polymer used in the present invention preferably has a glass transition point in the

range from 10°C to 80°C. If the glass transition point is less than 10°C, the coating tends to easily be damaged at the time of slitting or punching, while if over 80°C, the coating is liable to turn white. More preferable lower
5 limit of the glass transition points are more than 25°C, 35°C, 45°C and 55°C, and more preferable upper limit of the glass transition points are less than 70°C and 65°C.

The method of causing the particulate polymer of the present invention to disperse in the epoxy resin is not
10 particularly limited. It is possible to mix different resins mechanically or emulsify them then mix them or perform emulsion polymerization in an acrylic modified epoxy resin solution to convert the acrylic resin to particulate polymer.

15 As the form of the particulate polymer, generally a spherical shape is preferred, but a hollow shape or egg shape or other irregular shape or a so-called hybrid shape with different compositions at the inside and outer periphery are also possible. Further, depending on the
20 affinity with the epoxy resin, sometimes a clear appearance is not exhibited. Considering the possibility of partially excessive pressure being applied at the time of slitting or other processing, a higher interface bondability of the epoxy resin and particulate polymer
25 would give a better processability, so there is no problem even if a clear appearance is not exhibited.

As the amount of addition of the particulate polymer, 1 to 30 parts by weight with respect to 100 parts by weight of the epoxy resin is suitable. If less
30 than 1 part by weight, the effect of the present invention does not appear, while if over 30 parts by weight, agglomeration or precipitation of the particulate polymer easily occurs and hinders handling.

The epoxy resin curing agent used in the present
35 invention is one which can cause the epoxy resin to cure. Usually the curing reaction is started by heating to a predetermined temperature. Specifically, there are acid

anhydride-based curing agents (anhydrous phthalic acid, hexahydrophthalate anhydride, tetrahydrophthalate anhydride, anhydrous pyromellitic acid, pyromellitate anhydride, etc.), aliphatic amines (diethylene triamine, triethylene tetramine, polyamide, 2-ethyl-4-methylimidazole, etc.), methaphenylene diamine, dicyandiamide, organic acid dehydrazide, aminimide, ketamine, tertiary amine salts, 3-fluoroboroamine salts, nylon, melamine resins, phenol resins, xylene resins, NBR, polysulfide, aniline resins, block isocyanate, acrylic resins, etc. Exhibiting particular good properties are melamine resins, resol-type phenol resins, block isocyanate, acrylic resins, etc.

The weight ratio of the epoxy resin curing agent should be 1 to 30 parts by weight with respect to 100 parts by weight of the esterification reaction product with the epoxy resin. If the epoxy resin curing agent is less than 1 part by weight, the heat resistance of the coating after bonding tends to become inferior, while if over 30 parts by weight, the curing agent will tend to become concentrated and white near the coating surface after being coated and dried.

Further, the coating weight is preferably 1 to 6 g/m², in particular 1 to 3 g/m². If less than 1 g/m², the bond strength tends to fall, while if over 6 g/m², the interlaminar factor tends to deteriorate.

Next, the conditions set for baking at the time of forming the coating on the electrical steel sheet are not particularly limited, but in a drying furnace set to 150 to 800°C such as in the usual practice, setting a sheet temperature of 100 to 300°C in a short time is preferable.

The mechanism of the present invention is assumed to be the reduction of the internal stress, but the details are not clear. Further, with the technology disclosed in Japanese Unexamined Patent Publication (Kokai) No. 62-50361, a glass transition point of under room temperature

is effective, but in an adhesive coating, the glass transition point of the particulate polymer should rather be in the range of 10°C to 80°C. Further, the particle size of the particulate polymer has a great effect on the bond strength. The reasons are not clear. However, an adhesive coating is used in a state with the epoxy resin layer formed extremely thinly on the surface of a steel sheet with an extremely small coefficient of heat expansion and a large rigidity compared with an organic resin. It is believed that factors different from the internal stress reducing mechanism of general organic resins are at work here.

FIG. 1 shows fractured surfaces of bonded parts of a sample obtained by bonding together bonding use surface-coated steel sheets coated and baked with resin compositions according to the present invention under conditions of 200°C x 10 kgf/cm² x 30 minutes (Fig. 1B) and a sample obtained by bonding together samples according to the prior art (Fig. 1A) - as observed by a scanning electron microscope. With the sample according to the prior art, the fractured part exhibits a smooth face showing that the fracture propagated quickly, as shown in Fig. 1A.

As opposed to this, with a sample according to the present invention, micro level relief patterns are caused at the broken part. Complex fracture propagation paths are seen, as shown in Fig. 1B.

From these results of observation, in the case of the resin composition according to the present invention, by forming "sea island structures" of acrylic resin particulates uniformly dispersed in a continuous phase of an epoxy resin, it is believed that the propagation of fractures is delayed and therefore the bond strength is improved.

Further, the shearing bond strength and the bond strength of the push apart test performed in the present invention exhibit different behavior. That is, in the

shearing strength test, no force acts in the direction perpendicular to the bonded surfaces of the steel sheets, while in the push apart test, there is a component acting in the direction perpendicular to the bonded surfaces.

5 The peeling behavior of the adhesive coating naturally change. If considering the electromagnetic force acting on the stacked core of an actual motor etc., the push apart test is assumed to give a strength required for an actual stacked core more reliably.

10 Normally, as the method for measurement of the strength in the push apart direction, the peeling strength measurement method is the general practice. However, the inventors studied this and as a result found that if measuring the peeling strength using electrical
15 steel sheet, since the samples break, it is difficult to smoothly peel apart the bonded samples, the variation becomes extremely great, and measurement is difficult.

Further, with the method of preparing thin steel sheets for measurement of the peeling strength, the
20 surface conditions differ from electrical steel sheet in which various steel ingredients are added, so there is a worry of the behavior becoming different from that of an actual stacked core.

Therefore, the inventors discovered that, as the
25 method of measuring the bonding strength in the push apart direction, by pushing a wedge into a core sample obtained by stacking and bonding, it is possible to measure the bond strength in the push apart direction. Japanese Unexamined Patent Publication (Kokai) No. 62-
30 50361 used the peeling test method (ASTM D1876) as the method of measurement of the bond strength, but the present invention creates the push apart test method for electrical steel sheet and compared this with the prior art. FIG. 2 shows the peeling test method of the prior
35 art and the push apart test method used for measurement in the present invention.

EXAMPLES

Coils of nonoriented electrical steel sheet after finishing annealing (thickness 0.5 mm, silicon content 0.5%) treated by a known method were used as the test materials in the original state without being coated with an ordinary insulating coating. Next, the epoxy resin emulsions and epoxy resin curing agents shown in Table 1 and the particulate polymer shown in Table 2 were successively mixed to prepare the treatment solutions shown in Table 3. These treatment solutions were coated on the sheets by a rubber roll type coating system, then the sheets were baked at a sheet temperature of 160°C so as to give coatings of the amounts described in the table.

Samples were cut out from the coils and evaluated as to the coating properties. The results are shown in Table 4. Next, the case of using coils coated and baked with the magnesium chromate-acrylic resin-based organic/inorganic mixed coating used for ordinary electrical steel sheet to 1 g/m² as the test materials is shown in Table 5. Note that to convert the coating weight to thickness, it is necessary to change the conversion formula when for example the amount of coating is large and when it is small or when the surface roughnesses of the steel sheets differ, but in the case of coating of the present invention, the thickness is about 0.6 μm to 1 μm for an amount of 1 g/m².

Regarding the bond strength in the direction pushing apart the bonded surfaces, 40 samples cut out from each of the coils coated and baked with predetermined amounts of the different solutions to sizes of 2 cm x 3 cm were stacked, then fastened by special jigs. The stacks were heated and/or pressed at 200°C x 10 kgf/cm² x 30 minutes to bond them and thereby fabricate stacked cores, then a wedge shaped probe was pressed at the center of the stacked side surfaces and the loads when the stacked cores separated was measured.

Table 1

Name of solution	Epoxy resin	Epoxy resin curing agent	Glass transition point
Epoxy 1	BPA	AR	85°C
Epoxy 2	Acrylic modified BPA	PR	110°C
Epoxy 3	Acrylic modified BPA	-*	125°C
Epoxy 4	NR	PR	150°C
Epoxy 5	BPA	AR	30°C
Epoxy 6	BPA	AR	55°C
Epoxy 7	NR	AR	165°C

*: In Epoxy 3, the modified acrylic resin functions as a curing agent, so no curing agent is added.

5

Table 2

Name of solution	Resin composition	Particle size (μm)	Glass transition point
Particulate 1	EA+PVA+BA	0.2	10°C
Particulate 2	MMA+St+BA+HPMA	0.4	80°C
Particulate 3	MMA+EA+St	0.35	60°C
Particulate 4	PVA+PU	0.1	75°C
Particulate 5	PVA+EA+MA	0.3	40°C
Particulate 6	PU+PVA+EHMA	0.008	45°C
Particulate 7	PVA+PU	0.8	87°C
Particulate 8	PVA+MMA	0.23	-15°C
Particulate 9	St+MMA	0.15	130°C

*: Explanation of abbreviations in Tables 1 and 2

PBA: Bisphenol A type epoxy, NR: Novolak type epoxy, PR: Phenol resol type curing agent, AR: Amino resin curing agent, EA: ethyl acrylate, MMA: methyl methacrylate, St: Styrene, BA: butyl acrylate, PVA: polyvinyl acetate, PA: Polyethylene, PU: Polyurethane, HPMA: Hydroxypropyl methacrylate, MA: acrylic acid, EHMA: 2-ethylhexyl methacrylate

*: The parts in the tables are parts by weight by resin solid content conversion.

10

15

Table 3

Name of solution	Epoxy resin (100 parts by weight)	Particulate polymer	Remarks
Treatment solution 1	Epoxy 2	Particulate 1, 10 parts by weight	Invention
Treatment solution 2	Epoxy 2	Particulate 1, 5 parts by weight	Invention
Treatment solution 3	Epoxy 2	Particulate 2, 20 parts by weight	Invention
Treatment solution 4	Epoxy 1	Particulate 1, 8 parts by weight	Invention
Treatment solution 5	Epoxy 1	Particulate 2, 10 parts by weight	Invention
Treatment solution 6	Epoxy 1	Particulate 3, 10 parts by weight	Invention
Treatment solution 7	Epoxy 2	Particulate 3, 5 parts by weight	Invention
Treatment solution 8	Epoxy 4	Particulate 4, 5 parts by weight	Invention
Treatment solution 9	Epoxy 4	Particulate 1, 7 parts by weight	Invention
Treatment solution 10	Epoxy 3	Particulate 3, 5 parts by weight	Invention
Treatment solution 11	Epoxy 2	Particulate 6, 30 parts by weight	Particulate small and out of particle size
Treatment solution 12	Epoxy 1	Particulate 3, 0.5 parts by weight	Particulate out of added amount
Treatment solution 13	Epoxy 1	Particulate 1, 50 parts by weight	Particulate out of added amount
Treatment solution 14	Epoxy 3	Particulate 7, 15 parts by weight	Particulate large and out of particle size
Treatment solution 15	Epoxy 2	Particulate 8, 8 parts by weight	Particulate out of Tg point
Treatment solution 16	Epoxy 3	Particulate 9, 20 parts by weight	Particulate out of Tg point
Treatment solution 17	Epoxy 5	Particulate 3, 15 parts by weight	Epoxy out of Tg point
Treatment solution 18	Epoxy 6	Particulate 5, 20 parts by weight	Epoxy out of Tg point
Treatment solution 19	Epoxy 7	Particulate 3, 10 parts by weight	Epoxy out of Tg point
Treatment solution 20	Epoxy 2	No particulate added	No particulate added (prior art)

Table 4

	Treatment solution	Coating amount (g/m ²)	Bonding strength (kgf/cm ²)		Push apart (kgf) ^c	Blocking ^d
			Ordinary temp. ^a	High temp. ^b		
Ex. 1	Treatment solution 1	2.0	160	75	866	Good
Ex. 2	Treatment solution 2	2.2	155	50	671	Good
Ex. 3	Treatment solution 3	2.8	154	82	755	Very good
Ex. 4	Treatment solution 4	1.9	142	55	748	Good
Ex. 5	Treatment solution 5	2.3	134	80	841	Very good
Ex. 6	Treatment solution 6	2.1	147	49	633	Good
Ex. 7	Treatment solution 7	2.7	144	57	533	Very good
Ex. 8	Treatment solution 8	2.4	152	63	583	Good
Ex. 9	Treatment solution 9	1.6	154	69	775	Good
Ex. 10	Treatment solution 10	1.5	108	52	480	Very good
Comp. Ex. 1	Treatment solution 11	2.1	136	49	124	Good
Comp. Ex. 2	Treatment solution 12	2.9	141	41	231	Good
Comp. Ex. 3	Treatment solution 13	3.4	131	38	614	Poor
Comp. Ex. 4	Treatment solution 14	1.9	87	23	364	Very good
Comp. Ex. 5	Treatment solution 15	3.1	143	19	450	Fair
Comp. Ex. 6	Treatment solution 16	1.9	128	52	264	Good
Comp. Ex. 7	Treatment solution 17	3.1	163	16	735	Poor
Comp. Ex. 8	Treatment solution 18	1.8	133	26	636	Fair
Comp. Ex. 9	Treatment solution 19	2.1	96	86	112	Very good
Prior Art 1	Treatment solution 20	1.6	147	58	214	Very good

(Notes) a: Bonding force measured by press bonding at

pressure of 10 kg/cm² and temperature of 200°C for 60 sec, then shearing at ordinary temperature.

b: Bonding force measured by press bonding at conditions of "a", then heating to 150°C.

5 c: Maximum load measured when stacking 40 samples cut to 2 cm x 3 cm, bonding at 200°C x 10 kgf/cm² for 30 min, then pushing wedge (tip angle 7°) into center of stack side surface.

10 d: Stickiness evaluated after pressing at ordinary temperature for 72 hours at 20 kg/cm². Not sticky at all evaluated as "very good", somewhat sticky as "good", sticky, but no force required for peeling apart by hand as "fair", and force required for peeling apart by hand as "poor" with "good" or higher considered passing.

Table 5

	Treatment solution	Coating weight (g/m ²)	Bond strength (kgf/cm ²)		Push apart (kgf)	Blocking
			Ordinary temp.	High temp.		
Ex. 1	Treatment solution 1	1.4	113	36	461	Very good
Ex. 2	Treatment solution 2	1.3	102	44	270	Very good
Ex. 3	Treatment solution 3	1.5	104	31	344	Very good
Ex. 4	Treatment solution 4	1.6	127	33	416	Good
Ex. 5	Treatment solution 5	1.4	98	41	462	Good
Ex. 6	Treatment solution 6	1.3	119	40	311	Very good
Ex. 7	Treatment solution 7	1.3	112	38	217	Very good
Ex. 8	Treatment solution 8	1.6	102	31	238	Very good
Ex. 9	Treatment solution 9	1.1	137	43	357	Very good
Ex. 10	Treatment solution 10	1.3	121	38	360	Good
Comp. Ex. 1	Treatment solution 11	1.7	81	43	98	Very good
Comp. Ex. 2	Treatment solution 12	1.6	73	38	125	Good
Comp. Ex. 3	Treatment solution 13	1.5	67	29	166	Fair
Comp. Ex. 4	Treatment solution 14	1.4	88	31	155	Good
Comp. Ex. 5	Treatment solution 15	1.2	104	13	162	Fair
Comp. Ex. 6	Treatment solution 16	1.1	101	34	132	Good
Comp. Ex. 7	Treatment solution 17	1.3	105	10	241	Fair
Comp. Ex. 8	Treatment solution 18	1.5	89	23	155	Fair
Comp. Ex. 9	Treatment solution 19	1.6	34	39	93	Very good
Prior Art 1	Treatment solution 20	1.4	87	31	134	Very good

INDUSTRIAL APPLICABILITY

As described above, the present invention provides a surface-coated electrical steel sheet for bonding, by using a mixture of an epoxy resin or modified epoxy resin having a glass transition temperature (Tg) of 80°C to 150°C and an epoxy resin curing agent and a particulate polymer having a particle size of 0.01 to 0.5 μm dispersed therein, it is possible to reduce the drop in bond strength even with thin coating, possible to sufficiently secure bond strength in the direction pushing apart the bonded surfaces, and possible to reduce the drop in bond strength even when coating on an ordinary insulation film.

CLAIMS

1. A bonding use surface-coated electrical steel sheet characterized in that the surface of the electrical steel sheet has an insulating coating exhibiting
5 bondability by heating and/or pressing and in that said coating comprises a mixture of an epoxy resin or modified epoxy resin having a glass transition temperature (Tg) of 80°C to 150°C and an epoxy resin curing agent and
10 particulate polymer having a particle size of 0.01 to 0.5 μm .

2. A bonding use surface-coated electrical steel sheet as set forth in claim 1, characterized in that the Tg of said particulate polymer is 10°C to 80°C.

3. A bonding use surface-coated electrical steel
15 sheet as set forth in claim 1, characterized in that said particulate polymer is an acrylic-based resin.

4. A bonding use surface-coated electrical steel sheet as set forth in claim 1, characterized by
20 containing 1 to 30 parts by weight of the particulate polymer with respect to 100 parts by weight of epoxy resin.

5. A bonding use surface-coated electrical steel sheet as set forth in claim 1, characterized in that said epoxy resin is modified by an esterification reaction
25 with an acrylic-based resin in advance.

6. A bonding use surface-coated electrical steel sheet as set forth in any one of claims 1 to 5,
30 characterized in that an electrical steel sheet formed on its surface with an organic/inorganic mixed insulating coating or an inorganic insulating coating is formed with an insulating coating having bondability comprised of an epoxy resin or modified epoxy resin and epoxy resin curing agent and particulate polymer dispersed therein.