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(54) **COMPOSITION AND METHOD FOR RESTORING AN ELECTRICAL CABLE AND INHIBITING CORROSION IN THE ALUMINUM CONDUCTOR CORE**

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(58) **Field of Classification Search** 174/25 C, 174/25 P; 427/117, 118, 387
See application file for complete search history.

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(57) **ABSTRACT**

Composition and method for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable and preventing corrosion of a central aluminum conductor of the cable by supplying the cable with an alkoxy silane composition. In one embodiment, the alkoxy silane composition includes dimethyldi(n-butoxy)silane.

18 Claims, No Drawings

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**COMPOSITION AND METHOD FOR
RESTORING AN ELECTRICAL CABLE AND
INHIBITING CORROSION IN THE
ALUMINUM CONDUCTOR CORE**

CROSS-REFERENCES TO RELATED
APPLICATIONS

This application is a continuation of PCT/US2007/08641, filed Dec. 4, 2007, which claims the benefit of U.S. Provisional Application No. 60/884,837, filed Jan. 12, 2007. Each application is expressly incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Typical solid dielectric shielded electrical cables include a number of copper or aluminum strands surrounded by a semi-conducting or insulating strand shield, a layer of insulation, and an insulation shield. This design of solid dielectric shielded cables is known for having a useful life of 25-40 years. In some instances, the life span of a solid dielectric shielded cable is shortened when water enters the cable and forms micro-voids in the insulation layer. These micro-voids develop throughout the insulation layer in a tree-like shape, collections of which are sometimes referred to as water trees.

Water trees are known to form in the insulation layer of electrical cables when medium to high voltage alternating current is applied to a polymeric dielectric (insulator) in the presence of water and ions. As water trees grow, they compromise the dielectric properties of the polymer until the insulation layer fails. Many large water trees initiate at the site of an imperfection or a contaminant, but contamination is not a necessary condition for water trees to propagate.

Water tree growth can be eliminated or retarded by removing or minimizing the water or ions, or by reducing the voltage stress. Another approach requires the injection of dielectric enhancement fluid from an external fluid source into interstices located between the strands of the cables. U.S. Pat. No. 5,907,128 provides a detailed description of such an approach. The fluid reacts with water inside the cable and oligomerizes to form a fluid with dielectric enhancement properties. The oligomerized fluid functions as a water tree retardant and provides other beneficial properties.

One drawback to the injection of dielectric enhancement fluid is that conventional fluids produce alcohol in the process of reacting with water inside the cable. Over time and under certain conditions, the alcohols produced by the hydrolysis of the currently used dielectric enhancement fluids, under certain conditions, may cause corrosion of the cable's central aluminum conductor.

Despite the advances made in remediating electrical cables through the use of dielectric enhancement fluids, a need exists for an improved dielectric enhancement fluid that cannot result in corrosion of the cable's central conductor. The present invention seeks to fulfill this need and provides further related advantages.

SUMMARY OF THE INVENTION

The present invention provides compositions and methods for restoring an in-service solid dielectric shielded electrical cable and preventing corrosion in the central aluminum core.

In one aspect, the present invention provides a method for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable while at the same time preventing corrosion of the central conductor of the cable. In one

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embodiment, the method includes supplying the interstitial void volume in the region of the conductor with an alkoxy-silane composition. The composition includes an alkoxy-silane that is hydrolyzable in the void volume and produces an alcohol that is non-corrosive to the central conductor at temperatures up to and exceeding maximum cable operating temperatures of about 100° C.

In another aspect of the invention, a composition for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable is provided. In one embodiment, the composition is an alkoxy-silane composition that includes an alkoxy-silane that is hydrolyzable in the cable and produces an alcohol that is non-corrosive to the central conductor at temperatures up to and including about 100° C. In one embodiment, the composition includes dimethyldi(n-butoxy) silane.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides compositions and methods for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable while at the same time preventing corrosion of the cable's central conductor.

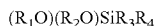
In one aspect, the invention provides a method for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable. In-service solid dielectric shielded electrical cables include a central conductor encased in an insulation jacket and include an interstitial void volume in the region of the conductor. In one embodiment of the method, the interstitial void volume is supplied with an alkoxy-silane composition to enhance the dielectric strength of the cable. Devices and methods for introducing a dielectric enhancement fluid into an in-service solid dielectric shielded electrical cable are known in the art. For example, U.S. Pat. No. 5,907,128 provides a description for injecting dielectric enhancement fluid from an external fluid source into interstices located between strands of the cable. U.S. Pat. No. 6,697,712 describes a distributed cable feed system and method for introducing dielectric enhancement fluid to an in-service cable. Each of these patents and application are incorporated by reference in their entirety.

In the method, an alkoxy-silane composition is supplied to the interstitial void volume of the cable in the region of the conductor. The alkoxy-silane composition includes an alkoxy-silane that is hydrolyzable in the volume to produce an alcohol, the mixture of the alkoxy-silane and the hydrolysis products including the alcohol, is non-corrosive to the central conductor at temperatures up to and including about 100° C., the temperature achieved by certain electrical cables during use.

Methanol and ethanol are alcohols produced by dielectric enhancement fluids (e.g., dimethyldimethoxysilane, dimethyldiethoxysilane, phenylmethyldimethoxysilane) traditionally used to remediate in-service solid dielectric shielded electrical cables. Although dielectric enhancement fluids that produce methanol and ethanol are initially advantageously useful in enhancing the dielectric strength of the cable, because these fluids produce alcohols that under some circumstances that may exist in a cable system are corrosive to the cable, corrosion problems may arise and have arisen in practice when such enhancement fluids are used. Corrosion caused by these alcohols is a greater problem at elevated temperatures approaching the boiling point of the alcohols their reactions produce. The alkoxy-silane composition useful in the method of the invention does not include an alkoxy-silane that produces an alcohol (e.g., methanol or ethanol) that

is corrosive to the central conductor at temperatures through the standard operating range of the cable up to and including about 100° C.

In one embodiment, the alkoxysilane composition useful in the method of the invention includes a dialkoxysilane having the formula:



wherein R_1 and R_2 are independently selected from the group consisting of C_4 and C_5 alkyl groups; and

wherein R_3 and R_4 are independently selected from the group consisting of C_1 alkyl, C_2 alkyl, C_3 alkyl, phenyl, and tolyl groups.

C_4 alkyl groups include n-butyl, s-butyl, and i-butyl groups. C_5 alkyl groups include n-pentyl, s-pentyl, and i-pentyl groups.

In one embodiment, R_1 and R_2 are n-butyl groups.

In one embodiment, R_1 and R_2 are n-pentyl groups.

In one embodiment, R_3 and R_4 are methyl groups.

In one embodiment, R_1 and R_2 are n-butyl groups and R_3 and R_4 are methyl groups.

In one embodiment, R_1 and R_2 are n-pentyl groups and R_3 and R_4 are methyl groups.

As noted above, the alkoxysilane composition useful in the method of the invention includes a dialkoxysilane. Representative dialkoxysilanes include dibutoxysilanes and dipentoxysilanes. The alkoxysilane of the composition is hydrolyzable in the void volume of the cable. Suitable dibutoxysilanes include di(n-butoxy)silanes, di(s-butoxy)silanes, and di(i-butoxy)silanes. Suitable dipentoxysilanes include di(n-pentoxysilanes, di(s-butoxy)silanes, and di(i-butoxy)silanes.

In one embodiment, the alkoxysilane useful in the method of the invention is a dialkyldialkoxysilane. In one embodiment, the dialkyldialkoxysilane is a dialkyldibutoxysilane. In one embodiment, the dialkyldialkoxysilane is a dialkyldipentoxysilane.

Representative dialkyldialkoxysilanes useful in the method of the invention include dimethyldibutoxysilanes, diethyldibutoxysilanes, dipropyldibutoxysilanes, dimethyldipentoxysilanes, diethyldipentoxysilanes, and dipropyldipentoxysilanes. It will be appreciated that that the butoxysilanes can be n-butoxysilanes, s-butoxysilanes, and i-butoxysilanes, and that the pentoxysilanes can be n-pentoxysilanes, s-pentoxysilanes, and i-pentoxysilanes.

In one embodiment, the alkoxysilane is an aryl dialkoxysilane. Representative aryl dialkoxysilanes include phenylmethyldibutoxysilanes, phenylmethyldipentoxysilanes, diphenyldibutoxysilanes, and diphenyldipentoxysilanes. It will be appreciated that that the butoxysilanes can be n-butoxysilanes, s-butoxysilanes, and i-butoxysilanes, and that the pentoxysilanes can be n-pentoxysilanes, s-pentoxysilanes, and i-pentoxysilanes.

In one embodiment, the alkoxysilane composition includes dimethyldi(n-butoxy)silane (DMDB). In one embodiment, the alkoxysilane composition includes dimethyldi(n-pentoxysilane (DMDPT).

The alkoxysilanes useful in the invention can be made by treating a suitably reactive silane (e.g., dimethyldichlorosilane, phenylmethyldichlorosilane, diphenyldichlorosilane) with excess alcohol (e.g., a butanol or a pentanol). Removal of excess alcohol by distillation provides the dialkoxysilane product. Dimethyldi(n-butoxy)silane is commercially available (Geleste, Morristown, Pa.).

The alkoxysilane composition useful in the method of invention can further include a hydrolysis catalyst to render the alkoxysilane reactive to water in the interstitial void volume of the cable, thereby rendering the alkoxysilane more

readily hydrolyzable. Suitable catalysts include, but are not limited to, tetra(isopropyl) titanate (TiPT). The catalyst is present in the alkoxysilane composition in an amount from about 0.1 to about 0.3 percent by weight based on the total weight of the composition.

In one embodiment, the alkoxysilane composition further includes a dye. The dye is a non-functional dye and is used in the composition to permit visual determination of excess alkoxysilane composition supplied to the cable. Suitable dyes include, but are not limited to, Morplas Blue commercially available from Sun Belt Chemicals (Rock Hill, N.C.). The dye is present in the alkoxysilane composition in an amount from about 0.01 to about 0.05 percent by weight based on the total weight of the composition.

As noted above, the alkoxysilane composition useful in the method of the invention includes an alkoxysilane that is hydrolyzable to produce a final mixture including an alcohol that is non-corrosive to the central conductor at temperatures up to and including about 100° C. As used herein, the term “non-corrosive” refers to the lack of corrosive effect on the central conductor of an in-service solid dielectric shielded electrical cable by the alcohol produced by the hydrolysis of the alkoxysilane supplied to the interstitial void volume in the region of the conductor. An alcohol is determined to be “non-corrosive to the central conductor” at a specified temperature when aluminum conductor material is subjected to a mixture of the alkoxysilane and the alcohol produced by the hydrolysis of the alkoxysilane in quantities that might be reasonably expected to occur in a cable environment at the maximum cable operating temperatures specified and for a specified time when no corrosion, pitting, mass loss, gas evolution, or solution color change is observed in a laboratory corrosion test.

A method for determining whether an alcohol is non-corrosive to the central conductor is described in the Example. The Example describes a corrosion test method and results for dimethyldimethoxysilane (DMDM), dimethyldiethoxysilane (DMDE), dimethyldi(n-propoxy)silane (DMDPr), dimethyldi(n-butoxy)silane (DMDB), and dimethyldi(n-pentoxysilane (DMDPT), which on hydrolysis produce methanol, ethanol, n-propanol, n-butanol, and n-pentanol, respectively.

The results clearly show that significant corrosion of the aluminum conductor occurs in the presence of methanol and ethanol, some corrosion occurs in the presence of n-propanol, and no measurable corrosion occurs in the presence of n-butanol or n-pentanol.

The results demonstrate that methanol, ethanol, and propanol are corrosive to the aluminum conductor at temperatures up to and including 100° C. Accordingly, alkoxysilanes that hydrolyze to produce methanol, ethanol, or propanol will be corrosive to the aluminum conductor of an electrical cable under conditions of use.

The results also demonstrate that n-butanol and n-pentanol are not corrosive to the aluminum conductor at temperatures up to and including 100° C. Accordingly, alkoxysilanes that hydrolyze to produce n-butanol or n-pentanol will not be corrosive to the aluminum conductor of an electrical cable under conditions of use.

In another aspect, the invention provides an alkoxysilane composition useful in enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable while at the same time preventing corrosion of the cable’s central aluminum conductor. The alkoxysilane composition includes an alkoxysilane that is hydrolyzable in the interstitial void volume in the region of the conductor or in the polymer insulation to produce an alcohol that is non-corrosive to the

central conductor at temperatures up to and including about 100° C. In one embodiment, the alkoxy silane is a dialkyl-dialkoxy silane. In one embodiment, the alkoxy silane is an aryl dialkoxy silane.

Suitable dialkyl dialkoxy silanes include dibutoxy silanes and dipentoxysilanes. Representative dibutoxy silanes include dimethyldibutoxy silanes, diethyldibutoxy silanes, and dipropyldibutoxy silanes. Representative dialkyldipentoxysilanes include dimethyldipentoxysilanes, diethyldipentoxysilanes, and dipropyldipentoxysilanes. It will be appreciated that the butoxy silanes can be n-butoxy silanes, s-butoxy silanes, and i-butoxy silanes, and that the pentoxysilanes can be n-pentoxysilanes, s-pentoxysilanes, and i-pentoxysilanes.

Suitable aryl dialkoxy silanes include phenylmethyldibutoxy silanes, phenylmethyldipentoxysilanes, diphenyldibutoxy silane, and diphenyldipentoxysilane. It will be appreciated that the butoxy silanes can be n-butoxy silanes, s-butoxy silanes, and i-butoxy silanes, and that the pentoxysilanes can be n-pentoxysilanes, s-pentoxysilanes, and i-pentoxysilanes.

The alkoxy silane composition useful in the method of invention can further include a hydrolysis catalyst to render the alkoxy silane reactive to water in the interstitial void volume of the cable, thereby rendering the alkoxy silane more readily hydrolyzable. Suitable catalysts include tetra(isopropyl) titanate (TiPT).

In one embodiment, the alkoxy silane composition further includes a dye. The dye is a non-functional dye and is used in the composition to permit visual determination excess alkoxy silane composition supplied to the cable.

The following example is provided for illustrating, not limiting, the invention.

EXAMPLE

Corrosion Test Method and Results for Alkoxy silane Compositions

In this example, corrosion of the central aluminum conductor of an electrical cable by alkoxy silane fluids is described.

The method for determining corrosion (conductor mass loss) was as follows.

Strand preparation. Strands from field-aged cable (150 mm² conductor with 30 aluminum strands) were cut into 2 inch lengths (-/+ 1/16 inch). The strands were prepared for testing by rinsing with nitric acid and then drying the strands according to ASTM G1. The dried strands were then weighed and immersed in the test fluid within 2 hours of cleaning.

Fluid preparation. Test fluid (alkoxy silane) (150 g) was added to a clean, dried 500 mL PYREX Erlenmeyer flask. TiPT catalyst was added to the test fluid to provide a catalyst concentration of 0.2% by weight. The mixture of test fluid and catalyst was swirled for 1 minute to ensure mixing. Add the alcohol (5 or 10% by weight) to the mixture of test fluid and catalyst and swirl for 1 minute to effect mixing.

Test Procedure. Add the strands prepared as described above to the flasks containing test fluid, catalyst, and alcohol mixture such that the strands are submerged in the mixture. Seal the flask with a stopper modified to include a reflux condenser. Submerge the flask in an oil bath such that the level of oil in the bath matches the level of fluid in the flask. Heat the contents of the flask in an oil bath at 100° C. (or at the boiling point of the fluid mixture if less than 100° C.) for 250 hours (8 hours a day). After heating for 250 hours, remove the

strands from the flasks, clean the strands according to ASTM G1, and weigh within 2 hours.

Test Results. The loss of mass from the strands tested as described above was recorded and the results tabulated in Table 1. The mass loss values in the table represent the average of three runs (triplicate), except for dimethyldimethoxy silane (DMDM) (5% methanol) and dimethyldi(n-pentoxy) silane (DMDPt) were conducted in duplicate. In Table 1, "DMDM" refers to dimethyldimethoxy silane, "DMDE" refers to dimethyldiethoxy silane, "DMDPr" refers to dimethyldi(n-propoxy) silane, "DMDB" refers to dimethyldi(n-butoxy) silane, and "DMDPt" refers to dimethyldi(n-pentoxy) silane. Mass Loss/Day was calculated based on Total Mass Loss.

Dimethyldimethoxy silane (DMDM) and dimethyldiethoxy silane (DMDE) were obtained from commercial sources (e.g., Dow Corning, Midland, Mich.; Geleste, Morristown, Pa.). Dimethyldi(n-propoxy) silane (DMDPr) and dimethyldi(n-pentoxy) silane (DMDPt) were prepared as described above by reaction of dimethyldichlorosilane with n-propanol and n-pentanol, respectively. Dimethyldi(n-butoxy) silane (DMDB) was obtained from Geleste, Morristown, Pa.

TABLE 1

Comparison of Mass Loss for Alkoxy silane Fluids.			
Test Fluid	Alcohol (%)	Mass Loss Total (%)	Mass Loss/Day (%)
30 DMDM**	methanol 5%	0.85	0.08
DMDM	methanol 10%	12.87	1.24
DMDE*	ethanol 5%	7.24	4.20
DMDE*	ethanol 10%	11.42	9.76
DMDPr	n-propanol 10%	0.47	0.04
35 DMDB	n-butanol 5%	0.00	0.00
DMDB	n-butanol 10%	0.00	0.00
DMDPt**	n-pentanol 10%	0.00	0.00

*Experiments reached completion and removed before 250 hours.
**Average of 2 runs.

As clearly shown in Table 1, significant corrosion of the aluminum conductor occurs in the presence of methanol and ethanol, some corrosion occurs in the presence of n-propanol, and no measurable corrosion occurs in the presence of n-butanol or n-pentanol.

The results demonstrate that methanol, ethanol, and propanol are corrosive to the aluminum conductor at temperatures up to and including 100° C. Accordingly, alkoxy silanes that hydrolyze to produce methanol or ethanol will be corrosive to the aluminum conductor of an electrical cable under conditions of use.

The results also demonstrate that n-butanol and n-pentanol are not corrosive to the aluminum conductor at temperatures up to and including 100° C. Accordingly, alkoxy silanes that hydrolyze to produce n-butanol and n-pentanol will not be corrosive to the aluminum conductor of an electrical cable under conditions of use.

While illustrative embodiments have been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.

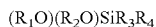
The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable and preventing corrosion of an aluminum central conductor encased

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in an insulation jacket and having an interstitial void volume in the region of the conductor, comprising:

supplying the interstitial void volume with an alkoxysilane composition comprising a dialkoxysilane having the formula:



wherein R_1 and R_2 are independently selected from the group consisting of C_4 and C_5 alkyl groups; and wherein R_3 and R_4 are independently selected from the group consisting of C_1 alkyl, C_2 alkyl, and C_3 alkyl.

2. The method of claim 1, wherein the composition further comprises a hydrolysis catalyst.

3. The method of claim 1, wherein the composition further comprises a non-functional dye.

4. The method of claim 1, wherein the C_4 alkyl group is selected from the group consisting of n-butyl, s-butyl, and i-butyl groups.

5. The method of claim 1, wherein the C_5 alkyl group is selected from the group consisting of n-pentyl, s-pentyl, and i-pentyl groups.

6. The method of claim 1, wherein R_1 and R_2 are n-butyl groups.

7. The method of claim 1, wherein R_1 and R_2 are n-pentyl groups.

8. The method of claim 1, wherein the dialkoxysilane is a dialkyldibutoxysilane.

9. The method of claim 1, wherein the dialkoxysilane is selected from the group consisting of a dimethyldibutoxysilane, a diethyldibutoxysilane, and a dipropyldibutoxysilane.

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10. The method of claim 1, wherein the dialkoxysilane is dimethyldi(n-butoxy) silane.

11. The method of claim 1, wherein the dialkoxysilane is a dialkyldipentoxysilane.

5 12. The method of claim 1, wherein the dialkoxysilane is selected from the group consisting of a dimethyldipentoxysilane, a diethyldipentoxysilane, and a dipropyldipentoxysilane.

10 13. The method of claim 1, wherein the dialkoxysilane is dimethyldi(n-pentoxy) silane.

15 14. A method for enhancing the dielectric strength of an in-service solid dielectric shielded electrical cable and preventing corrosion of an aluminum central conductor encased in an insulation jacket and having an interstitial void volume in the region of the conductor, comprising supplying the interstitial void volume with an alkoxysilane composition comprising a dialkoxysilane selected from the group consisting of a dimethyldibutoxysilane and a dimethyldipentoxysilane.

20 15. The method of claim 14, wherein the dialkoxysilane is dimethyldi(n-butoxy) silane.

16. The method of claim 14, wherein the dialkoxysilane is dimethyldi(n-pentoxy) silane.

25 17. The method of claim 14, wherein the composition further comprises a hydrolysis catalyst.

18. The method of claim 14, wherein the composition further comprises a non-functional dye.

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