INFLUENCE OF ADDITIVES ON THE WATER-TREEING IN XLPE INSULATED CABLES

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ABSTRACT

For MV cables installed in wet conditions, in order to demonstrate their durability, the main standards ask for a long term test (generally 2 years) in water and under electrical stress .

To develop new solutions more easily, small scale tests have been proposed to compare the behaviour of different materials, for example the ashcraft test. Using this laboratory scale test, trials have been made to measure the impact of different additives. The authors present the laboratory method, and the results obtained on insulations containing different natures and levels of peroxide and antioxidants.

KEYWORDS

MV cable insulation additives water-treeing.

INTRODUCTION

Depending on the used extrusion equipment, the insulation process of the MV cables can be slightly different:

- On a classic CCV extrusion line, compounds are used at delivery state. The additives, and in particular the peroxide and anti-oxidant, are dispersed properly in the polymer matrix by the supplier. In this case, the solid state of the additives is useful to avoid evaporation during delivery and storage, and the compound is just introduced in the extruder, with all cleanliness and handling precautions.

- On lines fitted with injection, the cable maker works with virgin polyethylene, and the additives are added on a liquid form, and injected in the extruder. This technology needs a proper dosing system, and is successfully used for a long time. In this case, the anti-oxidant, which can be solid or liquid, is dissolved in the liquid peroxide. Some safety rules have to be fulfilled, due to the vapour pressure of the peroxide.

The aim of this paper is to compare the behaviour regarding the water trees generation of the insulations obtained with the 2 technologies.

Water trees generation

There are two kinds of trees: the electrical tree and the electrochemical one.

The electrical trees appear when the maximum electric field at a suitable location is near the breakdown point. Generally it is admitted that partial discharges, which are not measurable individually, grow in micro-cavities and produce sharp hole at the tip, where the electric field is transferred. If micro-cavities don’t exist at the beginning, they are created by an electromechanical fatigue, in points of concentration of electric field. Heating due to dielectric losses can increase this fatigue.

The electrochemical trees are less clear than the electrical ones. They consist of multitudes of micro-channels (less than 1µm in diameter) that form a kind of fog. The presence of water or a solution in the cable insulation and the application of voltage are two essential conditions for the onset of electrochemical trees. They are often called water Trees.

There are two types of electrochemical trees: the bush-type trees (Vented tree) and the bow tie trees. The bush-type trees can be either electrical or electro-chemical. They develop from defects closed to conductive screens. They present a variety of forms: algae, herbs, feathers, ferns, clouds... The general direction of growing is that of electric field.

To generate a bush like tree, it is necessary to have a conducting tip (such as a needle) down in the insulation and an electrode, generally flat and in contact with the other side of the material. The tree is now growing where the electric field is strongest, generally just at the tip.

The bow tie trees are also of electric or electro-chemical nature. They are only observed from inclusions (impurities, micro-voids) distributed in the insulation. These trees are parallel to the electric field, they are shaped bow, always oriented in the same direction, inclusion forming their center. This type of tree is less dangerous in the operation of the cable than bush-type trees. Indeed, observations have shown that some cables, still in use, have within them a large number of bow-tie trees.

Method

In our case, we will focus in particular on electrochemical trees of bush type. The parameters which must be taken into consideration are:

Solution in presence:

To produce electrochemical trees in cable insulation, it is necessary to immerse them in water or to introduce moisture into the wiring. The trees grow mainly from the internal conductive shield, and from contaminants in the insulation, but rarely from the external shield, even when the water is outside.

Water has also been found in the channels of the trees.

As water impurities play a role in the initiation and propagation of trees, salts like $CuSO_4$, NaCl, $CaCl_2$ are used to increase the conductivity of the water. However, it was found that excessive concentration of salt has an adverse effect on the development of trees.

Electric field:

To produce electrochemical trees in the insulation of a cable, it is necessary to apply an alternating electrical field. The speed of propagation of trees generally increases with the square or cube of the voltage. The frequency also has an effect; it can vary as a power n of the frequency, n being between 0.6 and 0.7. It seems however that this law is valid only in a limited frequency. The voltage should be high enough to allow the development of trees, but must not exceed a certain threshold to avoid breakdown.

Temperature:

The time of initiation of trees decreases when the temperature increases. In addition, a temperature gradient, such as in the cable service makes the emergence of trees from the internal conductive shield easier.

Stress in material:

A fairly large mechanical stress has the effect of confining the tree in a plane perpendicular to its direction. In cables, the radial stress due to cooling can lead the water trees in longitudinal direction and delay its development.

The diverging field test is used primarily to evaluate the bush-type trees coming from the surface defects of the insulation. These defects are simulated by prints performed by precision needle filled with water. This test evaluates the bow type trees located in the volume of the insulation. The level of the voltage gradient at the forefront of the print is estimated by the following formula:

$E = 2U / (r \ln (1 + 4d / r))$, where :

E: electric field peak (kV / mm)

U: applied voltage (kV)

r: radius of curvature of the print (mm)

d: distance between electrodes (mm)

Preparation of the samples

The XLPE samples used for the test are obtained by moulding: they have a general shape of plate, with a diameter of 20 cm, and a thickness of 4 mm.

The materials, in general, are pellets, which are extruded to produce a melt. After, this melt is moulded by compression at 190 °C for 15 min under a press.

For the formulations prepared in the laboratory, the additives are added by mixing in a rotating barrel before extrusion

To generate water trees, the prints preparation is very critical. The useful part of the sample is 35 mm in diameter and 4 mm thick. The prints are located in the centre of plates. The diameter of the plates is deliberately larger than the active area to prevent circumvention of electric field.

We practice then boot prints of trees. For this, precision needles (3µm in diameter at the tip) are used. At first, they are cleaned with ethanol. The control of the cleanliness of the surface and the radius curvature of the needles are carried out under an optical microscope coupled with an image analyzer (Analysis software) at a magnification of x80.

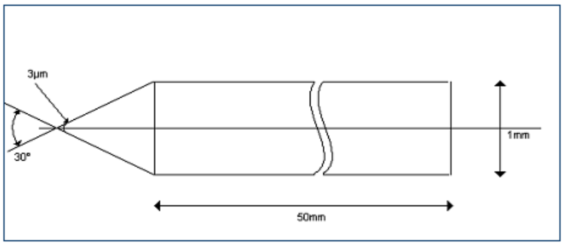

Figure 1: Dimensions of needles

• Once selected, the needle is welded with a soldering iron on a piston needle holder. (The power of the iron must be large enough to heat the medium: at least 75W). A 60 % tin solder was used for better conductivity of electricity.

• Adjusting the needle penetration is assured through the same microscope and software as those used previously. We have chosen to make prints of 1 mm (+ / - 0.1 mm) deep.

• The needle insertion does not alter the local structure around the footprint (creation of micro-cracks). This is why the needle and the samples are heated for 24 hours at 60 ° C just before performing the printing. This process is used to remove residual cross-linking and eliminate internal stress due to the operation of the moulding. The temperature of 60 ° C is chosen to avoid changing the internal structure of our specimens. 10 prints are produced by sample. We consider that a needle should be changed every 60 impressions All operations seen earlier must be renewed.

• The samples are then cleaned with ethanol, before examining the surface.

• Skirts are stuck with a sealant that also serves as seal. The sealant used is a transparent silicone sealant.

• After drying for 24 hours, the skirts are filled with the conductive liquid.

• Covers are placed on the skirts to reduce the evaporation of water. A screw press is coming on the lid to make a pressure on the lower electrode. This allows a better contact between the insulation and the lower electrode.

• The top electrode is placed in the hole of the cover provided for this purpose. It must be dipped in water. A screw is placed at the top to keep the electrode in place and avoid bad contacts.

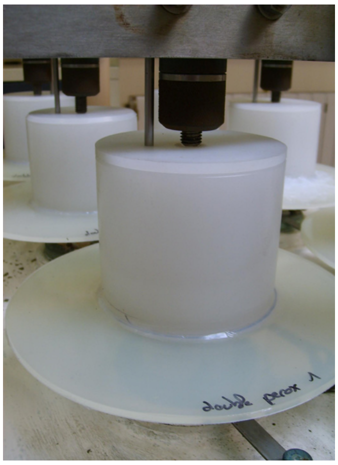

Figure 2: picture of the device

Test conditions

• The solution used consists of distilled water mixed with 3% NaCl. If the water height falls too much due to evaporation, distilled water is added during the test.

• The temperature is maintained at 23+/- 3°C

• The tests are undertaken at a power frequency (50 Hz),

The tests are carried out for 750 hours at 15 kV, with sample collected every 150 hours.

• The test table contains 24 pieces: 3 samples for 8 different materials. All samples were manufactured with strictly same process. The samples are connected in parallel.

Sampling for optical observation

The preparation of specimens for visual examination is an important point of the study. This can be summarized as follows:

• After removing the residual water, aged plates are dried in an oven at 60 ° C for 30 minutes.
• The central part with prints is cut and extracted from the plate. In a second step, it is cut with a microtome into slices varying from 120 to 500 µm depending on the location of prints, (about 100 slices).

• The strips are then placed in a boiled solution (rhodamine mixed with distilled water) for about 2 hours and a half. This treatment is intended to colour the water trees, which are translucent at the origin.
• After staining, each slide is cleaned with ethanol, to remove the excess of rhodamine from the surface.

• Each strip is then placed between two glass slides cleaned with ethanol. This helps to maintain a completely flat viewing area. The inspection of all slices is done under an optical microscope coupled to an image analyzer.

Results

Each sample was marked with 10 prints, so we have 10 measurements per sample. The trees were measured on the longer length (1)

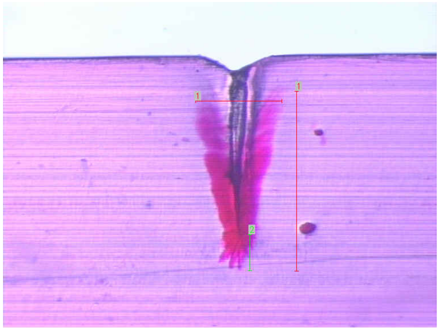

Figure 3: measurement of the tree

This is especially the measurement 1 which determines the danger of the tree against the material. The approximations are + / - 10 µm.

Influence of the type of the insulation

To study the influence of the additives on the behaviour of insulation in wet conditions, we have in a first step compared existing compounds of the market, the base polymer, and an insulation made by peroxide injection

The different tested materials are:

- WTR XLPE compound, right to use **(A)**
- WTR XLPE compound, right to use **(B)**
- Thermoplastic LDPE, used for silane injection **(C)**
- XLPE compound, right to use **(D)**
- XLPE compound, right to use **(E)**
- XLPE insulation, silane crosslinked (Sioplas) **(F)**
- XLPE insulation, with peroxide solution injection **(G)**
- Thermoplastic LDPE, used for peroxide injection **(H)**

The following graph provides an overview of the classification of materials tested in terms of their resistance to trees growing; the size of water trees are represented with relative numbers.

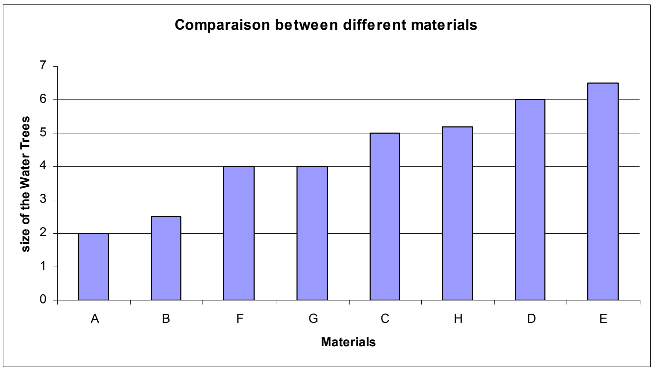

Figure 4: comparison of relative size of water trees

This comparison shows that the WTR XLPE (A) has the best behaviour. Material (B), which is also a WTR compound from the market shows a interesting result. At the other end, classical homopolymer compounds, used for medium or high voltage applications (D) and (E) show the higher sensibility to water trees. Just under the homopolymer compounds, we find the 2 thermoplastic resins, used one for silane application (C), the other for peroxide injection (H). The corresponding cross-linked materials, the (F) one, of Sioplas type, and the (G) with peroxide injection, show intermediate results, between the WTR and homopolymer compounds from the market.

We also note that all the trees have a relatively similar configuration, except for copolymer where the growth is moving in the transverse direction of the sample.

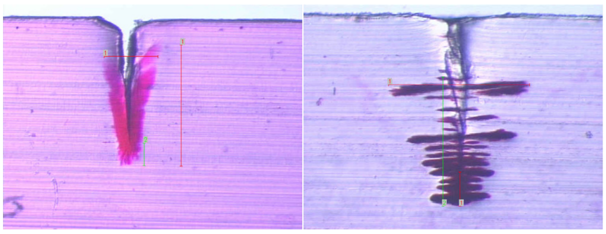

Figure 5: shapes of water trees

We can conclude from this comparison that the WTR compounds give the best results. Through these experiences, we could also assume that the cross-linking helps to reduce the development of water trees (comparison C-F and H-G)

On another hand, it is also true that the length of the trees depends on the nature of the additives (peroxide and anti-oxidant) used to crosslink the polymer (comparison E and G).

Impact of the additives

To study in more details the influence of the cross-linking system on the resistance of the material against the water trees, we have compounded some XLPE formulations, and made WTR evaluations.

The base formulation is the H one of the previous range. This formulation contains a homo-polymer, cross-linked with a solution containing a mixture of antioxidant 1 dissolved in liquid peroxide.

The tested materials are the following:

- XLPE insulation, with peroxide and antioxidant 1 solution **(H)**
- The level of peroxide in the injected insulation is doubled **(L)**
- The level of antioxidant in the injected insulation is doubled **(M)**
- The anti-oxidant 2 replaces, the antioxidant 1 in the injection solution **(N)**
- The level of anti-oxidant 2 is doubled in comparison with the previous insulation **(O)**

The following graph gives a general view of the results obtained after exposition to WTR test

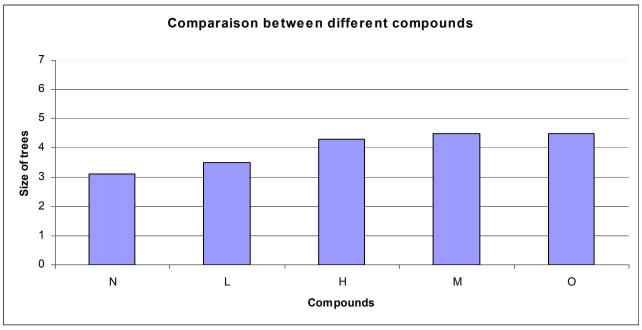

Figure 6: impact of the additives on the water-trees size

The basic formulation H, based on LDPE cross-linked with a solution containing liquid peroxide and anti-oxidant, gives a relative size of water trees of 4.3

By doubling the amount of peroxide, the size of water trees decreases to a level of 3.5 (bar L). Obviously, this type of formulation will probably give some scorch in extrusion.

The graph M shows that increasing the anti-oxidant 1 doesn't help to reduce the height of the water-trees.

The compound N, where the anti-oxidant 1 is replaced with another type, gives an interesting result, with a relative height of 3.1, not so far from WTR compounds.

With the last compound O, as with the sample M, it is clear that a too high level of anti-oxidant doesn't help to reduce the water trees sensibility of XLPE insulation

CONCLUSION

As first conclusion of this presentation, based on ashcraft test, it is clear that the WTR compounds, containing specific additives in their formulations, remain pertinent solutions to protect MV insulations against water trees ingress.

This study shows also that between the WTR compounds and the classical homo-polymer compounds, the XLPE insulations using liquid peroxide solutions as cross-linking system, lead to a resistance to water treeing intermediate between WTR and homo-polymer compounds.

Furthermore, by increasing the cross-linking level, and with a suitable choice of anti-oxidant, it is possible to improve the behaviour of insulation regarding water trees generation.

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