Close and Return

3 kHz ACCELERATED GROWTH OF WATER TREES IN MEDIUM VOLTAGE EXTRUDED CABLES

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ABSTRACT

This paper describes results obtained with a pragmatic method to assess the resistance of medium voltage polymeric cable insulation to water treeing. Water trees (WT) are produced in 14 days in the polyethylene insulation of commercial cable samples by use of a high frequency, high voltage power supply. This method can be used to provide information for asset management and also to check the quality of new cables. A comparison with the 50 Hz (2 years) and 500 Hz (4 months) test for some new cables demonstrates the possible application of the method to a pre-qualification test.

INTRODUCTION

The initial objective of the method was to provide information on the remaining lifetime of old cables for asset managers who still have to manage many kilometres of first generation XLPE cables. In order to evaluate the resistance of old cables to water treeing, Laborelec decided to perform accelerated ageing test on cable samples immersed in salt water using a high frequency, high voltage power amplifier. After 14 days the examination of dyed slices allows the assessment of the resistance of real cables to water treeing.

Rapidly the use of this method to assess new cable samples was investigated and it appeared that the test can also be interesting to compare different materials taking into account the manufacturing process. Cables from different origins were tested with sometimes surprising results.

This paper presents the results obtained with the method e.g. a comparison for some new samples with the 50 Hz (2 years) and the 500 Hz (4 months) tests both carried at 3 U_0 and 40 °C, the influence of the type of insulation material and of the impurity content on the water trees growth and the possible use of the test for pre-qualification test or in the framework of a more global quality check of new cables.

CONTEXT

Water treeing is one of the major causes of premature failure of polyethylene cables. By increasing the insulation losses water treeing can initiate in some cases electrical trees (Figure 1) that lead to breakdown. The water tree issue is considered by most people as solved and indeed due to improvements in the design, the manufacturing process and the insulation compound the growth of water trees in new cables is drastically reduced. Presently two types of water tree retardant insulation material are largely used and are known as copolymer insulation (in fact a mechanical blend of Low Densisty PolyEthylene and ethylene acrylate copolymer) and homopolymer insulation with water tree retardant additives (high molecular weight polymer added in small quantity (< 1%)). Nevertheless the phenomenon of WT growth is not yet fully understood, mostly because of the large number of influencing parameters as voltage stress, frequency, availability of water, presence of contaminants, polymer structure and temperature. Nowadays, unfortunately neither theoretical nor practical models integrating all those parameters are accessible. In order to guarantee a minimum resistance to water treeing, long duration tests are performed during the qualification of new cable designs. The most widespread of these tests is performed at 50 Hz during 2 years (3 U_0;40 °C). The very long duration of this test emphasizes the utility of a test delivering equivalent information in only 14 days.

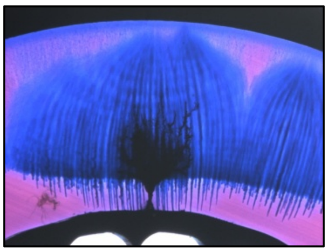

Figure 1: electrical tree

TEST SET-UP

Description

In order to perform an accelerated test we apply high frequency and high voltage to the insulation placed in a salt solution (Figure 2).

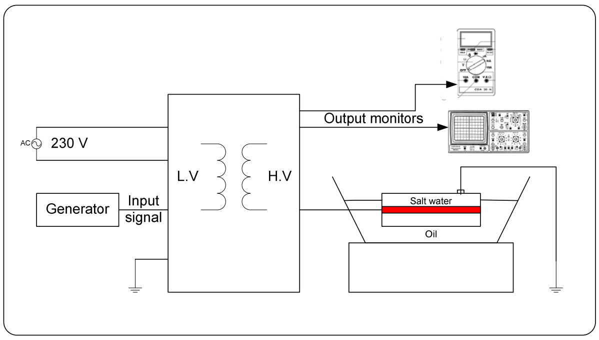

Figure 2: principle of the test

The experimental set-up consists in a 30 kV, 5 kHz, 40 mA power amplifier (Figure 3) and a cell containing salt solution immersed in a thermo-regulated oil bath (Figure 4) to avoid any electrical discharge at the connection of the high voltage lead.

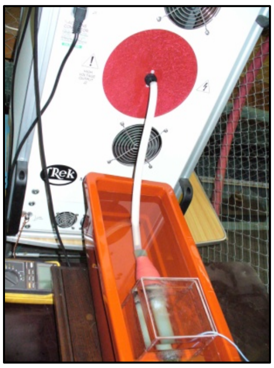

Figure 3: power amplifier

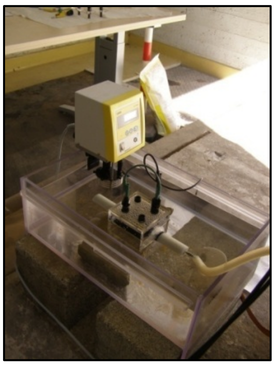

Figure 4: cable sample in salt water during testing

Test parameters

It has been reported that the most influential parameters for WT growth are the frequency, electric field strength and concentration of impurities [1].

Frequency

It has been demonstrated that up to at least 30 kHz WT growth is proportional to the applied frequency [2]. A frequency of 3 kHz allows a significant acceleration whilst staying far below the 30 kHz limit.

Voltage

The applied electric field is about 3,8 kV/mm on average which corresponds to roughly 1,5 the nominal voltage. The electrical stress enhancement is kept low in order to observe WT development in conditions close to those responsible for degradation under service conditions.

Impurity

The salt, by making the water conductive, allows the application of the voltage on the insulation of the sample and acts as impurities favouring the WT development. Effectively, during examination of highly degraded cables by water treeing, Cl^- ions were detected which comforts us in our choice.

Test duration

The duration of the test is 14 days which according to [2-3] should correspond to roughly 2 years at 50 Hz or 4 months at 500 Hz, which corresponds to the prescription of the Standard.

Length of the sample

The current that the amplifier must provide is proportional to the applied voltage and frequency and to the capacitance of the sample, which is proportional to its length. Due to power limitation in the amplifier, and because of the high frequency and high voltage, the length of the tested samples is limited to 10 centimetres.

Temperature

During the tests, the temperature is kept constant at 30 °C which is close to the in-service temperature for most distribution cables.

Preparation of the sample

The test can be performed in two different ways i.e. without the outer semi-conductive layer or with the outer semi-conductive layer. Each test delivers different results providing different information about the cable and its materials.

With the semi-conductive layer

A test with the semi-conductive layer will provide information on the cable and on the compatibility of the different layers (insulation and semi-conductor) of the cables. In order to get results similar to the 50 Hz or 400 Hz test a pre-conditioning of the sample at 55 °C in salt solution during 3 weeks is realized favouring the migration of the impurities through the semi-conductive layer.

Without the semi-conductive layer

This test provides more spectacular results with, generally, a lot of vented trees. This test is representative of the insulation material quality, including the manufacturing process.

Analysis of the sample after the ageing test

After the accelerated ageing test, 600 µm thick sections of the insulation material are taken, dyed with methylene blue (Figure 5) and examined with a stereomicroscope (Figure 6). The shape, length and quantity of water trees are recorded.

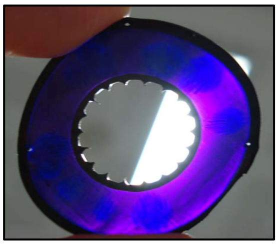

Figure 5: dyed slice

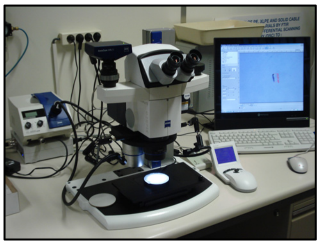

Figure 6: steremicroscope

COMPARISON BETWEEN INSULATION MATERIALS

Advancements have been brought at the insulation material level. Instead of the classic homopolymer, typically chemically crosslinked polyethylene, the use of so-called "copolymer insulation" (mechanical blend of a Low Density PolyEthylene and EthyleneButyl Acrylate copolymer) or homopolymer with water tree retardant additives (often simply referred to as TR-XLPE) is widespread. A difference in shape and length for the three different types of insulation material has been observed. The tests aiming to compare the insulation materials are performed without the external semi-conductor

Homopolymer insulation

Before the discovery of the WT phenomenon the insulation of all polyethylene extruded cables was "simple" homopolymer. The first generation of cables made with this material is particularly sensitive to WTs (see example in Figure 7). The length, up to 1415 µm after 7 days testing, and the quantity of WTs obtained with accelerated ageing tests confirm the poor behaviour of this generation of cables. Figure 8 shows the WTs observed after a 7 days test. We can observe that homopolymer polyethylene generates spherical water trees. This material is now widely replaced by "improved" polyethylene for cable designs that are not watertight.

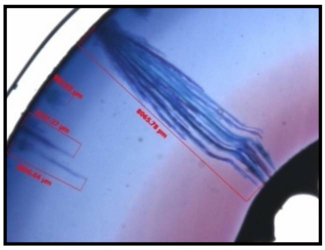

Figure 7: WTs inside the insulation of an aged cable

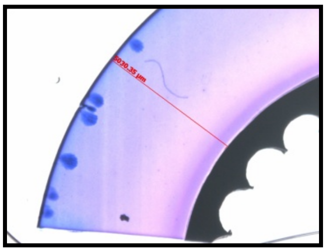

Figure 8: WTs after 7 days in a "homopolymer cable'

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Copolymer insulation

The addition of a copolymer (Ethylene Butyl Acrylate) has a beneficial effect on the WT growth. This improvement has been observed as well in lab as in the field [5]. The results obtained with the accelerated test confirm the former tests. Even if in some samples the quantity of WTs is impressive (see Figure 9) their length, generally in the range 100 to 300 µm, stays far below the length of the WTs developed in an homopolymer insulation. The observed WT are spherical or hand-like. In some more recent samples no water trees were discovered.

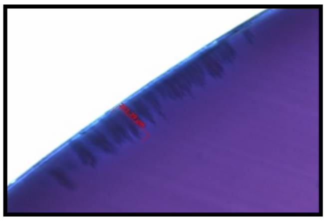

Figure 9: WTs after 12 days in a ”copolymer cable”

Homopolymer insulation with water tree retardant additives (TR-XLPE)

An alternative to the so called copolymer insulation is the use of water tree retardant additives in the insulation. Tests performed in lab and analysis of aged cables [6] show an improvement of the resistance of the material to WTs. Those improvements are also visible with the accelerated test which produces shorter trees with a constrained shape (see Figure 10). The length of the trees are comparable with the trees obtained in “copolymer insulation”. Differences in the dispersion, as well as, the manner in which the WT retarding components interacts with the WTs in the copolymer and additive WT retardant XLPE insulations, probably explain their different WT morphologies.

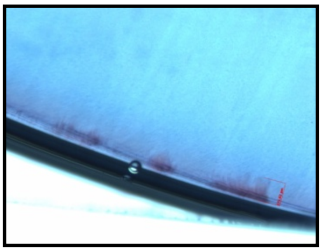

Figure 10: WTs in TR-XLPE

Comparison of the WT growth rates

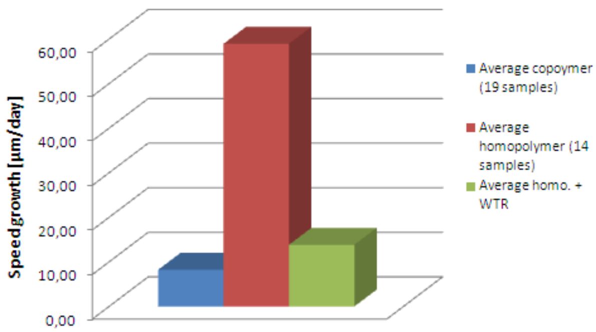

Figure 11: average speed of growth (µm/day)

As expected a comparison between the speed of growth in the different types of insulation (Figure 11) shows that since the first generation of cable produced with a homopolymer insulation material a great improvement has been realized. Only two sample of cable with a TR-XLPE insulation have been tested so far and therefore the growth speed cannot be considered as representative. The very low growth speed for copolymer insulation cable is explained by some samples that did not show any WT after the test. It has been assumed that in all cases the WTs nucleate rapidly and start growing from the roughened insulation surface shortly after the beginning of the test. The comparison of the speed growth is made on basis of vented trees which prove to be more “dangerous” than the bow-tie trees.

COMPARISON WITH AGED CABLES

Three examples of cables removed from the field are given in this paragraph. The same shapes obtained during natural growth in the field and during the accelerated ageing test attest that the growth mechanisms are the same.

In Figure 12, the form and the length of the vented trees found after the test are very similar to the vented trees detected before the test but in a much larger quantity. It demonstrates the ability of the test to create similar vented trees as those encountered in the field in a very accelerated way.

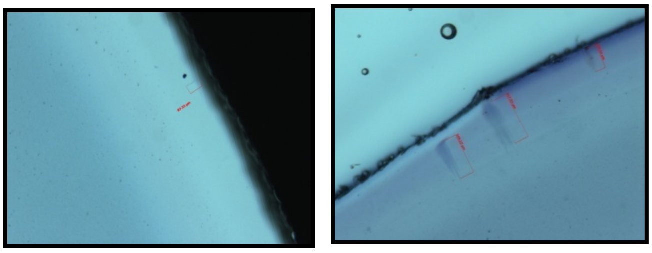

Figure 12: vented trees in a cable from 1976 before and after the accelerated ageing test

In Figure 13, the left picture is a first generation XLPE cable as removed from the ground after roughly thirty years in service. On the right picture a sample of the cable that was not buried was submitted to the accelerated test. Those pictures demonstrate that the shapes of the water trees are the same giving evidence that the growth mechanism is similar.

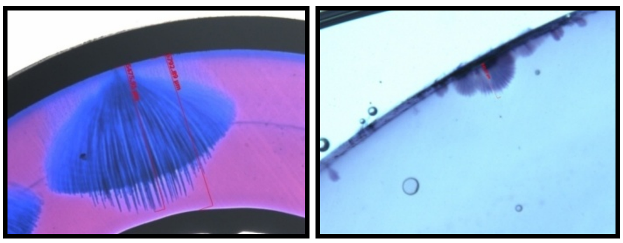

Figure 13: vented trees obtained in an aged cable sample before the accelerated test and on another sample after the test

A last example is given in Figure 14 where bow-tie trees coming from a cable removed from the field is similar to a bow-tie tree discovered after the accelerated test.

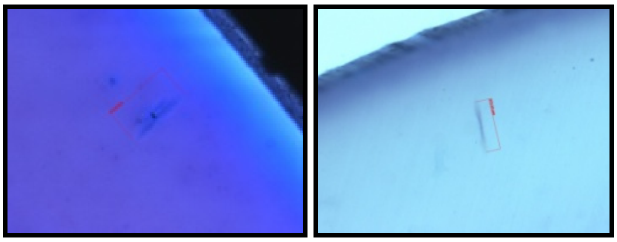

Figure 14: bow-tie trees obtained in an aged cable sample before the accelerated test and on another sample after the test

Figures 12 and 13 also attest of the influence of the manufacturing process on the growth of WTs. The two cables were produced in the years 70 but by two different manufacturers. They show an important difference in their resistance against water treeing visible aswell for the sample from the field as from the sample from the accelerated test.

INFLUENCE OF THE IMPURITY CONTENT

Through the years the purity of row materials (Figure 16) and the care during manufacturing has increased. The influence of this amelioration is clearly visible when assessing the resistance of cables to water treeing (Figure 15).

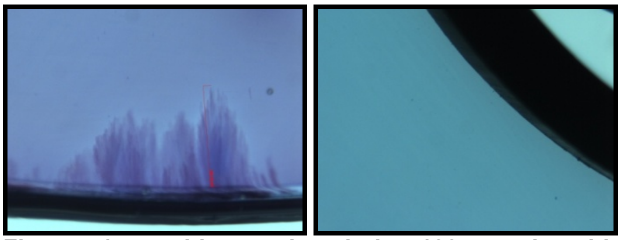

Figure 15: cable produced in 1994 and cable produced in 2006 tested with the outer semi-conductive layer

	Cable 1	Cable 2	Cable 3	Cable 4	Cable 5
year	1989	1994	2006	2008	2009
	%	%	%	%	%
S	0,073	**0,177**	**0,005**	0,011	0,023
Si	0,286	**0,131**	**0,022**	0,013	0,022
Ca	**2,647**	0,11			0,003
Zn	0,016	0,036		0,011	0,016
Cl	0,012	0,01			0,005
Pd	0,008	**0,009**	**0,01**	0,008	0,01
Mg	0,019	0,008			
Cu		0,006			
Fe	0,005	0,006			0,004
Ni	0,004				
K					0,001

Figure 16: evolution of the impurity content of the semi-conductive material with the years tested on cable samples

COMPARISON WITH OTHER TEST METHODS

Some tests are performed on polyethylene blocks using needles [7] to increase locally the electric field and favouring the initiation of water trees. These tests are useful to assess the quality of the insulation material but are not representative of a real piece of cable. In various countries water tree accelerated tests on full size medium voltage cables have been developed and some of them have become recognised standards. It is the case for the 2 years test at 50 Hz and for the 4 months test at 500 Hz. Those tests are described in [8]. The results (Pass or Fail) of these tests are expressed in terms of breakdown voltage and generally a visualization of the water trees is not performed. Unfortunately due to the short length of the tested samples the proposed method does not allow the application of a high voltage and therefore the criteria of the dielectric strength cannot be used. The assessment is based on the length, shape, and quantity of the detected water trees. According to [6] there is a relation between the dielectric strength and the length of the water trees and therefore the examination of the length of WTs gives us a reliable information. Another limitation as a consequence of the length is the length itself that reduces the probability to detect a bad portion of the cable. For the 50 Hz and 500 Hz test a length of 60 meters is required. Nevertheless the examination of several slices of a same sample and of several samples of the same cable show similar results in terms of length and concentration of WTs. Unfortunately only three samples were available and all samples are taken from recently manufactured cables. Figure 17 shows the water trees obtained with the different tests.

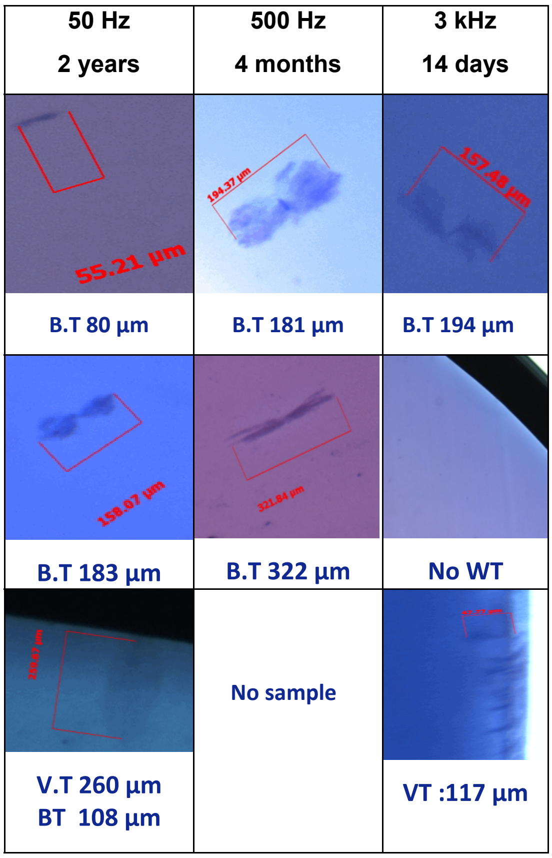

Figure 17: comparison with other test methods

QUALITY CHECK OF NEW CABLES

While some samples of new cables do not present any tree after the test, trees grew in other samples made with the same insulation material. Bow-tie trees seem to represent an image of contaminants present in the insulation and vented trees seem to be related to the impurity content of the semi-conductive layer. The growth of both of them is influenced by the type of insulation materials and by the manufacturing process. Therefore testing new cables delivers information on the quality of the material and on the quality of the process. In other words the test provides information on the quality of the cable itself. Figure 18 shows an example of a new cable produced in 2008 having a poor resistance to water treeing.

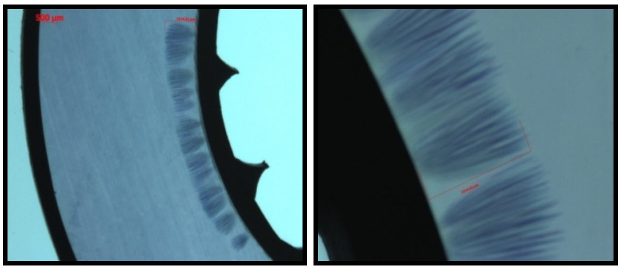

Figure 18: new cable with huge WTs after the accelerated ageing test

In addition to this test, each tested cable is analyzed by performing an Infra-Red spectrum of the insulation and of the semi-conductive materials in order to get more information about a possible link between used materials and their performance against water treeing and eventually highlight some incompatibility between insulation and semi-conductive materials.

A more in depth quality check consisting in mechanical tests, measurement of the impurity content and of some other important characteristics of the different constituents of the cable is also proposed. It allows a global quality assessment of the cable and provides reliable and quantitative information on the quality of new cable samples.

CONCLUSION

The tests realized with the method demonstrate its ability to create significant and repeatable water trees in real cable samples in only 14 days.

The comparison between water trees found in cables removed from the field and those measured in cables subjected to the accelerated test attest that the test reproduces the phenomenon responsible for the deterioration in service and provides useful information for the intrinsic life time determination.

The water treeing behaviour of different types of XLPE has been compared and the improvement due to the use of TR-XLPE of “copolymer insulation” and due to a better quality of materials and manufacturing process has been observed. The shape of the WTs is typical for each kind of insulation.

A comparison with the current tests was realized for three samples and shows that the obtained results are comparable with the 50 Hz (2 years) and 500 Hz (4 months) test in terms of obtained WTs. The short duration of the test (14 days) allows its use for a pre-qualification test of new cable design or of new materials.

The result of the test is representative of the quality of the cable and can therefore be used in the framework of a more global quality check.

REFERENCES

[1] J-P. Crine, 1998, “Electrical, Chemical and Mechanical process in Water Treeing”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 5 N°.5, October 1998, pp 681

[2] J-P. Crine, J. Jow, 2000, “Influence of frequency on water treeing in polyethylene” Conference on Electrical Insulation and Dielectric Phenomena”

[3] V.A.A; Banks, H. Faremo, E.F. Steennis, 1995, “An accelerated ageing test on the basis of 500 Hz for water treeing in cable, Jicable 1995

[4] E.F. Steennis, A.M.F.J. van de Laar, 1989, “Characterization test and classification procedure for water tree aged medium voltage cables”, Electra n° 125, 89 – 109,.

[5] A. Campus, M. Ulrich, 2003, , “20 years of experience with copolymer power cable insulation”, Jicable 2003

[6] S.R. Szaniszlo, 2003, “HFDA-4202 NT EC/HFDB-4202 NT EC Tree-Retardant Insulation – Reviewing 20 years of proven performance”, Technical Report

[7] IEC TS 61956, 1999, Methods of test for the evaluation of water treeing in insulating materials

[8] CENELEC HD 605 S1, 1994, “Electrical Cables – Additional Test Methods”