NEW TEST RESULTS WITH 3KHZ ACCELERATED GROWTH OF WATER TREES IN MEDIUM VOLTAGE XLPE CABLES

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ABSTRACT

This paper describes the new 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. The initial objective was to provide a source of information for asset management e.g. estimating the remaining lifetime of old installed cables known for their poor resistance to water treeing . However, rapidly it was discovered that WTs grow in all kinds of polyethylene cables but depending on the insulation type, the manufacturing process, the shape and speed of growth are different. This method can therefore also be used to assess the quality of new cables. A comparison for some new cable samples with the 50 Hz (2 years) test and with the 500 Hz (4 months) test is presented and demonstrates the possible application to a pre-qualification test.

INTRODUCTION

Water treeing is one of the major causes of premature failure of polyethylene cables, they increase the insulation losses and in some cases can initiate electrical trees 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. Nevertheless the phenomenon of WT growth is not yet fully understood and long test duration tests are still performed during the qualification of new cable designs.

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 cables. In order to evaluate the resistance of old cables to water treeing Laborelec decided to perform accelerated test on cable samples immersed in salt water using a high frequency, high voltage power amplifier (Figure 1). 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 during the last years with the method e.g. a comparison for some new samples with the 50Hz (2years) and the 500 Hz (4 months) tests, 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.

BRIEF DESCRIPTION OF THE TEST SET-UP

Figure 1: cable sample in salt water during testing

A more complete description of the test set-up can be found in [1]. It has been reported that the most influential parameters for WT growth are the frequency, electric field strength and concentration of impurities [2]. It has been demonstrated that up to at least 30 kHz WT growth is proportional to the applied frequency [3]. We chose 3 kHz for our test in order to obtain significant acceleration whilst staying far below the 30 kHz limit. The applied electric field is about 3,8kV/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. In order to favour WT development the insulation is placed in a salt solution. The duration of the test is 14 days which according to [3-4] should correspond to roughly 2 years at 50 Hz or 4 months at 500 Hz. Due to power limitation in the power amplifier, and because of the high frequency, the length of the tested samples is limited to 10 centimetres. After the accelerated ageing test, 600 µm thick sections of the insulation material are taken, dyed with methylene blue and examined with a stereomicroscope.

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. In [1] first results with the method showed a difference in shape and length for the three different types of insulation.

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 2).

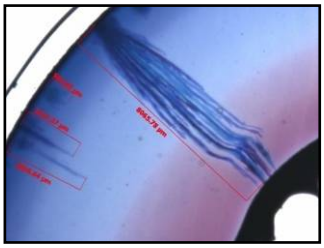

Figure 2: WT inside the insulation of an aged cable

The length, up to 1415 µm in 7 days, and quantity of WTs obtained with accelerated ageing tests confirm the poor behaviour of this generation of cables. Figure 3 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.

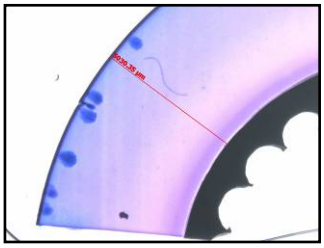

Figure 3: WTs after 7 days in a "homopolymer cable"

Copolymer insulation

The addition of a copolymer (EthyleneButyl Acrylate) has a beneficial effect on the WT growth. This improvement has been observed as well in lab as in the field [6]. The results obtained with the accelerated test confirm the former tests. Even if in some samples the quantity of WTs is impressive (see Figure 4) 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.

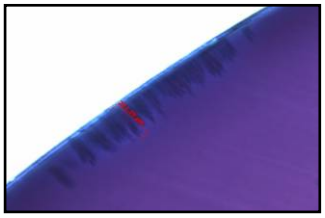

Figure 4: WTs after 12 days in a "copolymer cable"

Copolymer 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 [7] 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 5). 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.

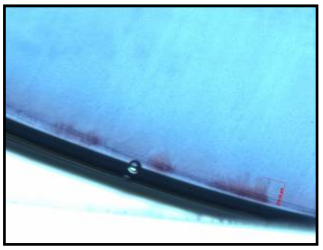

Figure 5: WTs in TR-XLPE

Comparison of the WT tree growth rates

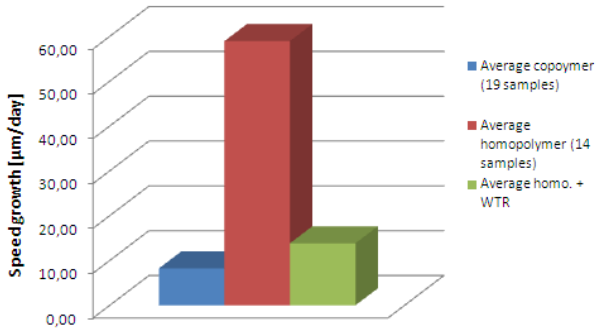

Figure 6: average speed of growth (µm/day)

As expected a comparison between the speed of growth in the different types of insulation 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 XLPE-TR 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.

COMPARISON WITH OTHER TEST METHODS

Some tests are performed on polyethylene blocks using needles 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 is 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 [5] there is a relation between the dielectric strength and the length of the water trees. 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 7 shows the water trees obtained with the different tests.

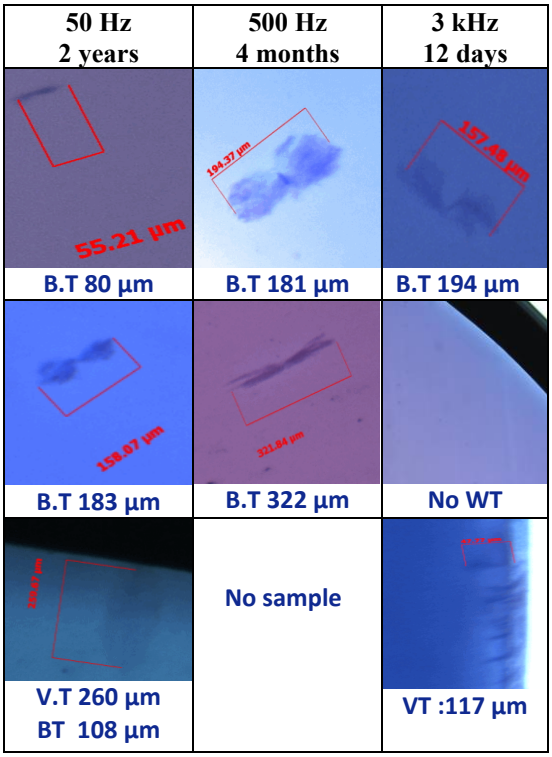

Figure 7: comparison with other tests

COMPARISON WITH AGED CABLES

Two 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.

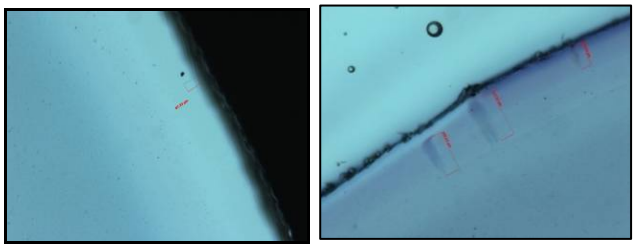

Figure 8: vented trees in a cable from 1976 before and after the accelerated test

In Figure 8, 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.

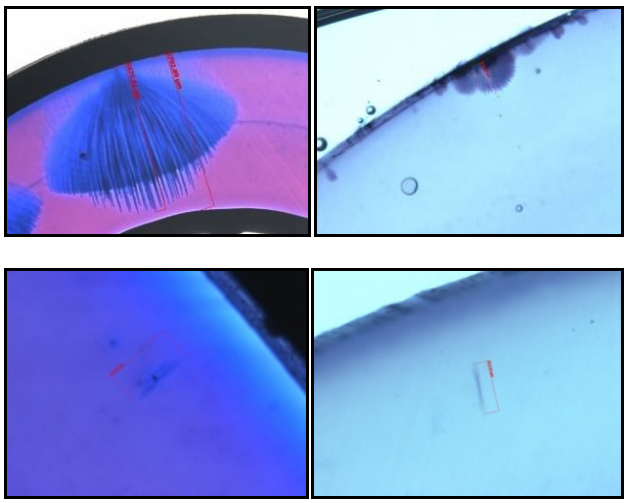

Figure 9: vented trees and bow-tie trees obtained in an aged cable sample before the accelerated tests and on a sample after the accelerated ageing test

INFLUENCE OF THE IMPURITY CONTENT

Through the years the purity of row materials (Figure 11) and the care during manufacturing has increased. The influence of this amelioration (Figure 10) is clearly visible when assessing the resistance of cables to water treeing.

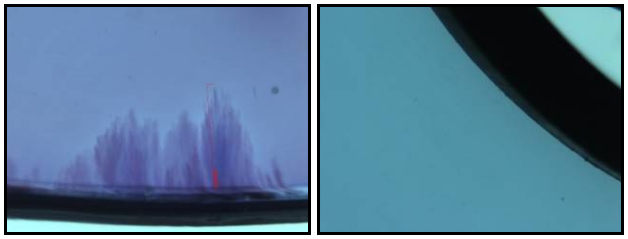

Figure 10: cable produced in 1994 and cable produced in 2006

	R23	R21	R669	R670	R677
	1989	1994	2006	2008	2009
	wt%	wt%	wt%	wt%	wt%
matrix	96,91	99,5	99,96	99,95	99,92
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 11: evolution of the impurity content of the semi-conductive material with the years tested on cable samples

QUALITY OF NEW CABLES

While some samples of new cables did 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. Therefore testing new cables delivers information on the quality of the material and on the quality of the process. In other word the test provides information on the quality of the cable itself. Figure 12 shows an example of a new cable having a poor resistance to water treeing. For each tested cable an Infra-Red spectrum of the insulation and semi-conductive materials is performed in order to test their performance and their compatibility.

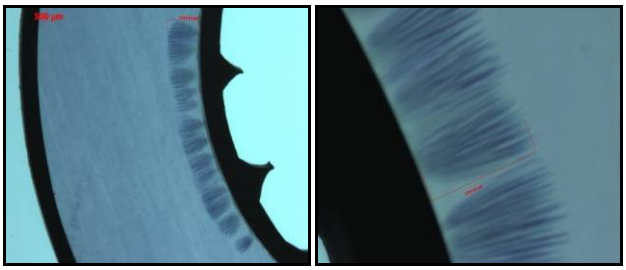

Figure 12: new cable with huge WTs after the accelerated ageing test

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 designs 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.

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