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WATER TREEING TEST RESULTS FOR DIFFERENT XLPE COMPOUNDS OBTAINED WITH NEEDLE TECHNIQUES

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ABSTRACT

This paper presents results from water tree studies based on a water needle test method. Several cables insulated with different XLPE insulation compounds, including peroxide-cured XLPE copolymer, peroxide- cured XLPE homopolymer and silane- cured XLPE have been evaluated.

In addition, the analysis of insulation morphology is presented for all dielectrics under consideration, as revealed by light microscopy.

The results from this study show that water tree growth by the water needle test method exhibits the same ranking of the different materials as seen in model cable tests.

It also shows that superior performance is demonstrated by enhanced copolymer XLPE insulation.

KEYWORDS

Water treeing, Needle test, Morphology, Model cables

INTRODUCTION

A variety of methods has been used to study the water treeing characteristics of polymeric insulations. Experiments in laboratory scale are typically made on press-molded objects. Studies have shown that it is possible to rank the performance of insulation compounds tested on laboratory objects in same order as the performance obtained by accelerated tests of cables [1].

By creating tiny water needles in objects taken directly from cables and subject them to electrical stress in presence of water, it is possible to study the true intrinsic water treeing properties of cable insulations.

This paper describes a water needle test method and results from tests of selected cable specimens with different insulation compounds. Morphology studies made of the cable samples is also reported.

MATERIALS

Crosslinked polyethylene (XLPE) is the most commonly used insulation material for modern MV cables. The XLPE is obtained by either peroxide or silane crosslinking of polyethylene. The peroxide XLPE exists in different compounds formulated to obtain long life and optimum processing and electrical performance. The classic peroxide XLPE is based on polyethylene homopolymer.

A broadly used later developed type is the so called copolymer XLPE that was developed in the 80ies for improved water tree retardant performance. This was obtained by addition of an acrylate copolymer to the polyethylene homopolymer base. A recent development of this category of copolymer XLPE has been made to further enhance the processing and water tree retardant performance.

The modern silane XLPE for power cable insulation is based on a reactor made polymer where the silane groups are attached to the polymer backbone simultaneous with the polymerization, i.e. a co-polymerization process.

For this study, commercially manufactured cables with the following insulation compounds have been selected:

- o XLPE 1: Classic (homopolymer) peroxide XLPE
- o Copo-XLPE 1:Copolymer modified WTR peroxide XLPE
- o Copo-XLPE 2: Copolymer modified enhanced WTR peroxide XLPE
- o Si-XLPE: Reactor made silane XLPE

ANALYSIS OF INSULATION MORPHOLOGY

Morphology, i.e. the structural organization of the insulation is one of the factors that determines the dielectric strength and the reliability of medium and high voltage cables, and in doing so morphology in the general case depends on the chemical composition and physical properties of insulation materials, as well as on their processing technology (extrusion equipment design, thermal conditions of extrusion, vulcanization and cooling).

The basic method for morphology analysis used in the present study is the computer-aided video enhanced microscopy, thus the spatial resolution is limited by the potentialities of the light microscope optics. DSC is used as an additional method.

Units of morphology of XLPE insulation in optical respect constitute phase objects, therefore methods which are sensitive to phase shift should be applied in their study. The present work employed the following main methods: dark-field microscopy (at low magnifications) and asymmetric illumination contrast (AIC), according to [2] for medium and large magnifications.

Morphology of homopolymer insulation.

At higher magnifications one can see that the basic large structure elements – clouds – split into separate regions which we will further refer to as “microclouds”. The concentration of microclouds in the cable under consideration is relatively small which means that it is rather homogeneous in terms of morphology. The same is also true for the copolymer and silane copolymer cables.

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Examples of clouds in homopolymer (XLPE1) are found in Figure 1-3.

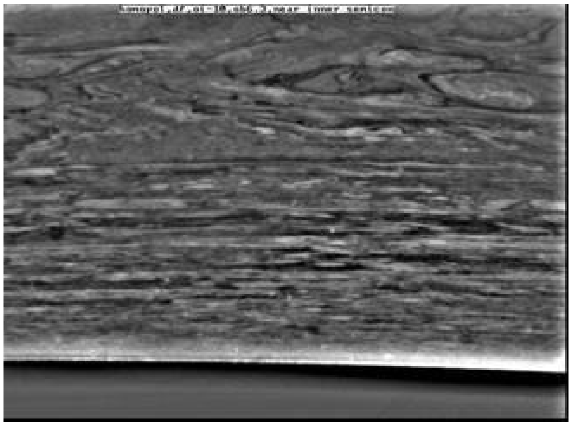

Figure 1: Dark field micrographs of clouds in homopolymer near the inner semiconductive screen

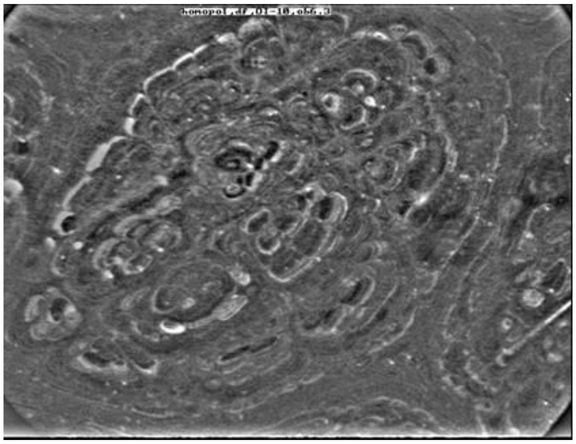

Figure 2: Dark-field video micrographs of clouds in homopolymer located in the middle of the insulation layer

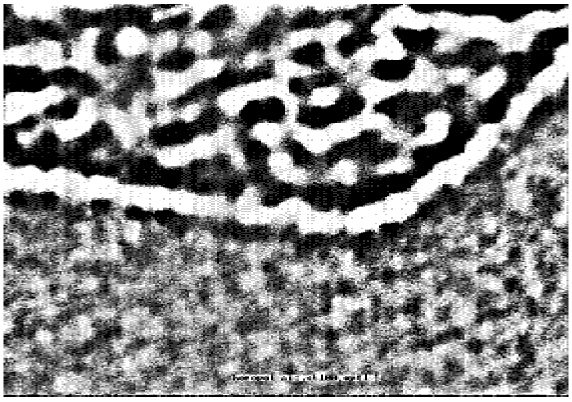

Figure 3: Separate microcloud in homopolymer. A symmetric illumination contrast (AIC), viewfield is 26 µm.

Morphology of copolymer insulation

Dark field micrograph is displayed in Figure 4 and AIC-micrograph is displayed in Figure 5

It was seen from video micrographs that within the capability of the applied methods, this insulation is in general similar to that considered above. At the same time it is shown in [3] that acrylate copolymer in this material forms a separate phase with particles having dimensions ~0.5µm. Even at the highest magnifications which are quite reasonable for video microscopy (~10000 times on a TV display of average size) we failed to see this phase. Probably it can be explained by the fact that the particle size of half a micrometer is approaching the theoretical limit of the light microscope resolution (approx 0.25µm) and the difference in optical properties of XLPE and copolymer within such small space limits cannot provide a sufficient contrast.

Figure 4: Example of cloud in copolymer. Dark field, frame width 2.5mm

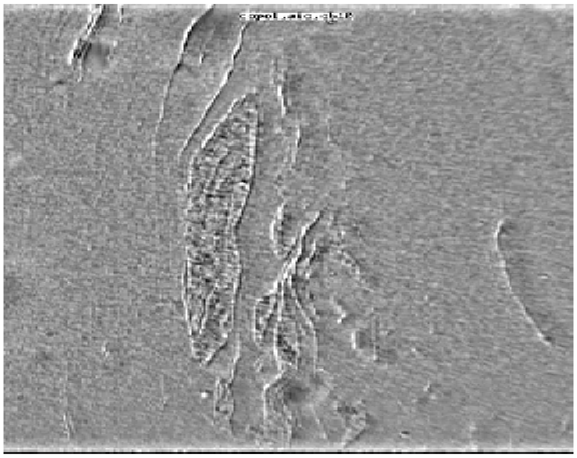

Figure 5: Microclouds in copolymer. AIC, frame width 370µm

Morphology of silane copolymer cable dielectric

The structural examination of the cable insulation specimen made of this material involved by far the greatest difficulties since the insulation morphology under the light microscope appears the most homogeneous or, which is the same, least contrast.

The image of stained insulation slice obtained using the bright field microscopy is shown in Figure 6 and in polarized light – in Figure 7.

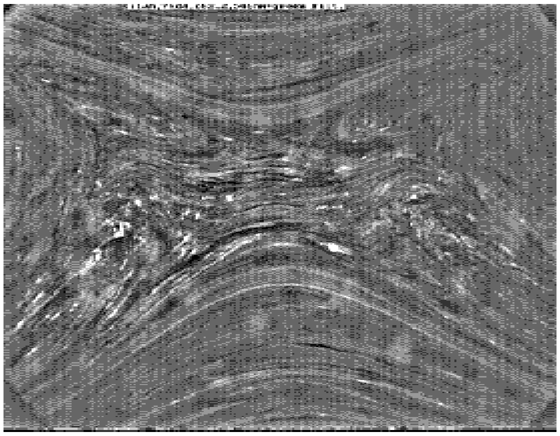

Figure 6: Silane XLPE; Area opposite the seam.

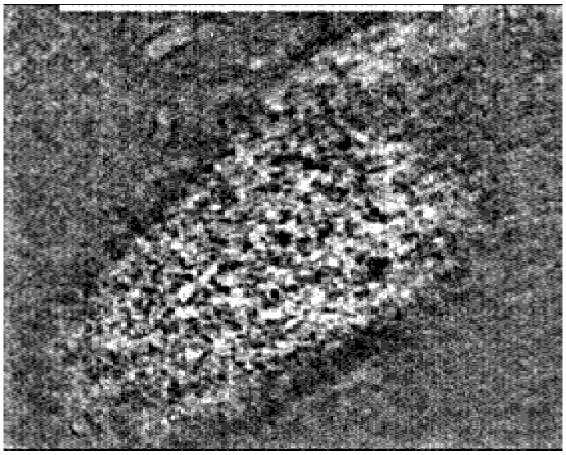

Figure 7: Micro cloud in Si-XLPE, crossed polars, frame width 48µm

To conclude the discussion of the morphology results for the insulations analyzed by computer video enhanced microscopy:

Reasoning from the experience of the earlier investigations we may state that the structures of the three analyzed insulation layers made of homopolymer, copolymer and silane-cured PE are, on the whole, rather homogeneous. This is a favorable fact, because the primary aim of the present work is a comparative study of properties of the different insulation materials, though being incorporated into finished cable products. From this point of view, any structural or other differences and heterogeneities, introduced into the materials while they are processed into cables, are undesirable as they cause additional uncertainty of the results.

The level of the insulation morphological heterogeneity and, respectively, the level of the optical contrast of the structure observed with a microscope depends on the amount (concentration) of the clouds/ microclouds and on the size differences of the embryonic spherulites comprising the clouds and the surrounding bulk material.

Additional information about finer structures that cannot be resolved with a light microscope is given by the DSC.

Melting temperatures and enthalpies for all the materials under consideration are given in Table 1.

Material	Melting Temperature (T_m),°C	Melting Enthalpy(H_m),J/g
XLPE-1	95.5-100	83-86
Copo-XLPE	103	98-99
Si-XLPE	105.5	100-103

Table 1: DSC analysis

The materials in Table 1 are arranged in order of increasing melting temperature (T_m). As may be seen from the data presented, the melting enthalpy (H_m) measured in the range of 40-115°C increases with the rise of T_m. The positive correlation between Tm and H_m values suggests that there are some differences in the fine crystalline phase structure of the compared materials. Higher H_m and T_m values may be indicative of a more perfect arrangement of the crystalline phase (larger crystallite dimensions) and /or of a higher crystallinity degree.

Water treeing test results.

The original specimens were short pieces of commercially manufactured cables. The actual test samples represented 3-mm thick slices, cut perpendicular to the cable axis: eight samples of this kind were prepared with each insulating system. The water needle was formed from the side of the inner semicon in such a way as to provide a 1.5 mm gap between the needle tip and the outer semicon. The water needles were filled with 0.3N NaCl water solution and served as HV electrodes; the outer semicon layers were grounded. All slices were thermally conditioned at 130^{0}C during 72 hours in the air atmosphere. After that they were installed in the testing cell, filled with silicone oil. The tests are being carried out at 12 kV/50 Hz, 40^{0}C.

As each WT grows not only from the very needle tip, but is somehow distributed along the needle surface, the measurements were carried out twice: within the ≈100^0 angle near the tip and at some distance from the tip− see diagram in Figure 8.

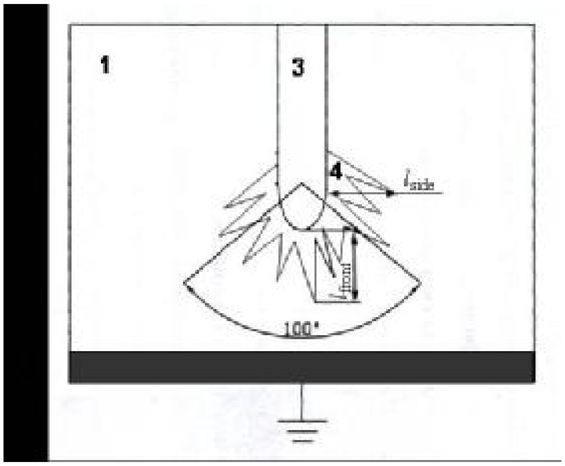

Figure 8: Block diagram of water tree length evaluation. 1=Insulation, 2=grounded semicon layer, 3=water needle, 4=water tree.

Figure 9 and 10 show the evolution of tree growth over time.

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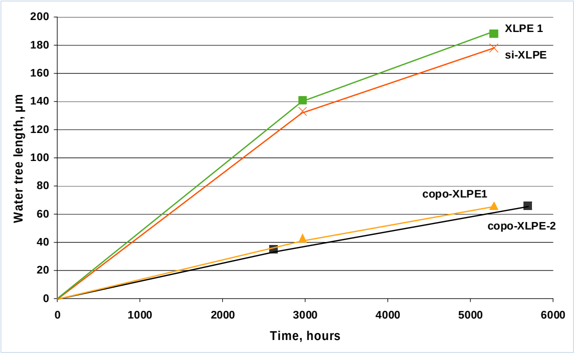

Figure 9: Tree growth from the needle tip (l_{front})

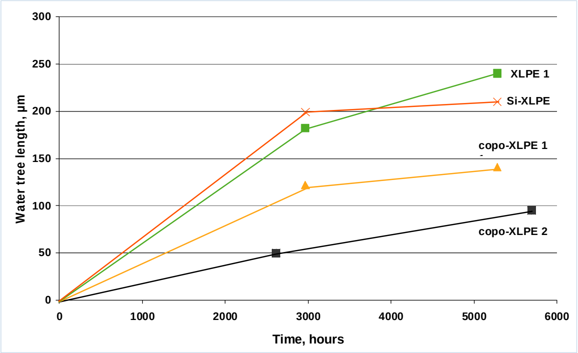

Figure 10: Tree growth from the needle side (l_{side})

The test data suggest the following ranking of the insulating materials, in terms of the WT sizes: the copo-XLPE 2 ranks first, the copo-XLPE 1 , second and the Si-XLPE ranks third. All homopolymer samples failed during the test.

The typical water trees grown in the XLPE copolymer and the silane-cured PE are presented in Figure 11 and in Figure 12 respectively. It should be pointed out that some (but not all) trees grown in the copolymer have a somewhat strange geometry – they look as if they tend to grow backwards as seen in Figure 13. At the same time the water trees grown in the Si-XLPE have, so to say, “leading channels”, which probably provide more extensive WT growth in this material.

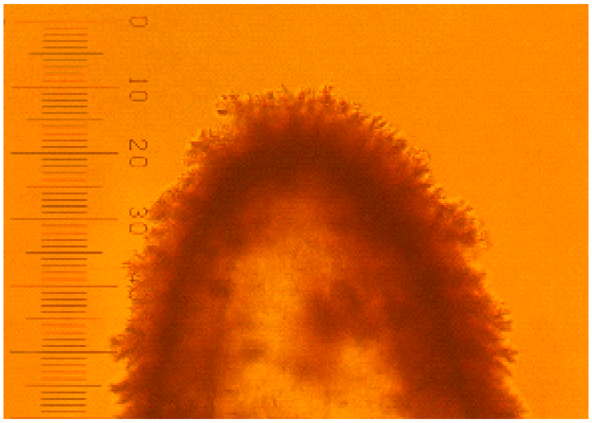

Figure 11: Example of water tree in copo-XLPE

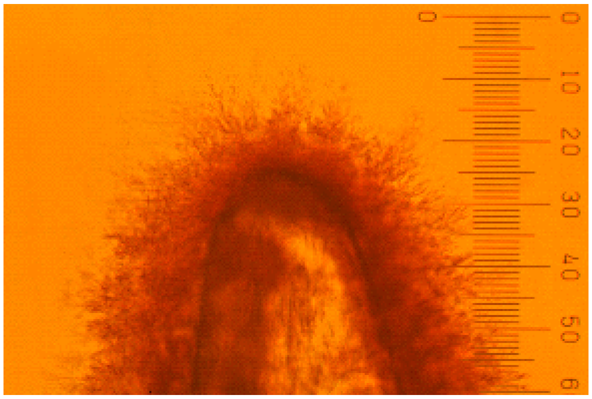

Figure 12: Example of water tree in Si-XLPE

Figure 13: Example of trees growing backwards in copo-XLPE 1. UV micrograph; tree stained with DNPH

Microspectral analysis of the water trees.

In addition to the analysis of water tree growth WT, microspectral analysis was carried out. Measurements of the absorbance spectra in the near- UV. region were made.

The spectra in the range of 300 - 400 nm were obtained for 160 µm- thick slices, both “intact” and treated with 2,4-dinitrophenylhydrazine (DNPH).

The spectra for the DNPH-stained samples are shown in Figure 14. Each spectrum in this figure is the mean of approximately 60-80 spectra and may be considered as a relative measure of chemical modification of the dielectric inside the tree (all absorbance spectra here were measured in relation to the non- treed areas in the slices).

It is generally accepted that water treeing in polyolefins is accompanied by oxidation [4]. The absorbance spectrum of the oxidized material treated with DNPH may serve as an indication of the oxidation degree [5].

The appearance of non-treated and DNPH- treated water trees is demonstrated in Figure 14 and 15 respectively. The photos were captured in the 300 nm - 400 nm spectral range. However since the applied UV filters (UFS- 6, LOMO, Russia) transmit also in the near IR range, the contrast of these images may be partially stipulated by the IR- component of light.

Both spectra show the same ranking of material as was shown by the water tree lengths.

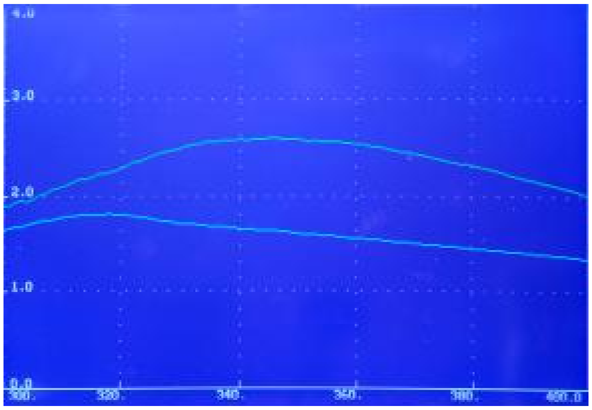

Figure 14: Absorbance spectra non-stained water trees copo-XLPE (bottom spectra) and si-XLPE (top spectra). (Optical density vs. spectral range, λ nm)

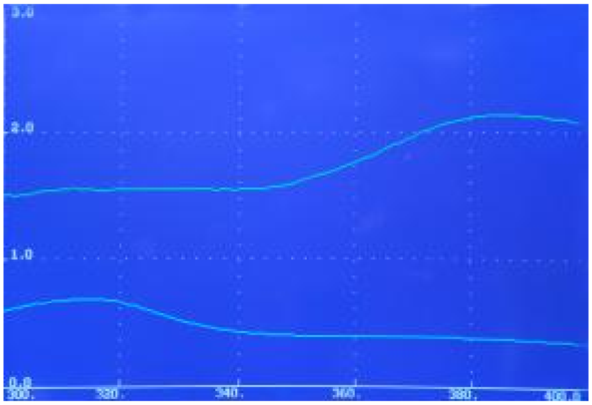

Figure 15: Absorbance spectra of water tress stained in DNPH in copo-XLPE (bottom spectra) and si-XLPE (top spectra). (Optical density vs. spectral range, λ nm)

Figure 16: UV photomicrograph of the water trees in si-XLPE stained with DNPH

MODEL CABLE TEST

The results from the water needle test have been compared with model cable test data of same category of insulation compounds.

The model cable test method is based on accelerated ageing of cables with 1.5mm2 conductor and 1.5mm insulation. The cable samples are aged in water for 1000 hours and the retained electrical breakdown strength is used as criteria [6]. The method has proven to be useful in product development as the results can be used to rank performance of different material systems with good correlation to corresponding ranking of performance in full size cable tests.

Results

The results from the model cable test in Figure 17 show the same ranking of the materials as seen in the water needle test. This clearly indicates that the evaluation of water tree growth from the water needles is an adequate method for investigation of treeing.

However, the particular tree pattern seen in the water needle test studies is not fully understood. There is clear suppression of tree growth from the side of the needles for copo-XLPE 2. As the electrical breakdown strength of this compound was very close to the initial breakdown strength before ageing, only a very weak indication of ageing was seen.

In order to further assess the ageing characteristic of the compound, the ageing time was extended to 2000 hours Figure 18.

This extended test shows that a reduction of electrical breakdown strength takes place also for copo-XLPE 2, but clearly at a considerably lower rate. The conclusion is that this compound is even more resistant to treeing as indicated by the growth of trees from the side of the water needle.

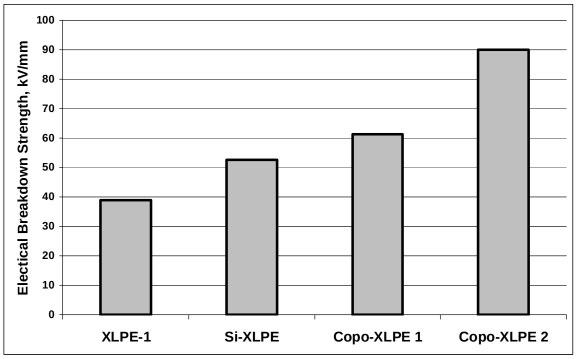

Figure 17. Electrical breakdown strength of model cables after wet ageing 1000h

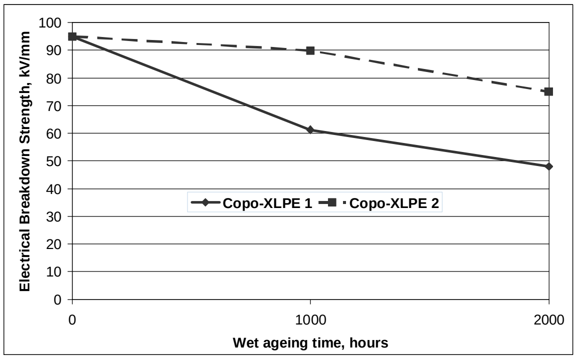

Figure 18: Electrical breakdown strength of model cables after wet ageing 1000h and 2000h

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CONCLUSION

The water needle test used within the framework of this study has the advantage that it utilizes the insulation samples cut from real cables, thus reproducing true cable dielectric morphology. At the same time the test results are not influenced by random defects, which inevitably contribute to the results of full-scale cable testing.

This water needle test shows the same ranking of insulation materials as the model cable test, namely:

Position	1	2	3	4
Material	Copo-XLPE 2	Copo-XLPE 1	Si-XLPE 2	XLPE 1

Microspectral analysis of water trees is the useful addition to the tree size measurements

REFERENCES

[1] Boström, J-O, Marsden, E, Hampton, N.H, Nilsson U.H. 2003. Assessment of cable performance as measured by a variety of accelerated ageing tests. Jicable-03

[2] Ahlinder.B, Fagrell.O, Johansson.K, Lindbom, L. Ethylene-Vinyl silane copolymers for medium voltage applications. 2005, Nordic Insulation Symposium – Nord-IS June 2005

[2] Kachar. B, 1985, Asymetric illumination contrast: A method for image formation for video light microscopy, Science, Vol 227, p.p 766-768.

[3] Nilsson U.H, Dammert R.C, Campus. A, Sneck. A, Jakosuo-Jansson, H, Morphology of polyethylene for power cable insulation: Effects of antioxidant and crosslinking.

[4] Xu J.J., Boggs S.A. The Chemical Nature of Water Treeing: Theories and Evidence. IEEE Insulating Magazine, vol. 10, Nr. 5, 1994, p.p. 29 – 37.

[5] Scheirs J., Delatycky O., Bigger S.W. et al. Staining Techniques for Detecting Localized Oxidation in High Density Polyethylene Powders and Films. Polymer International, vol. 26, p.p. 187 – 193, 1991.

[6] Land H.G, Schädlich H. 1991; Model cable test for evaluating the ageing behavior under water influence of compounds for medium voltage cables" Jicable'91 pp. 177-182