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WATER TREEING IN CHEMICALLY CROSSLINKED POLYETHYLENE

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The water tree resistance of chemically crosslinked polyethylene (XLPE) and of low density polyethylene (LDPE) were compared in order to elucidate whether the crosslinking itself influences or not the water tree propagation in polymer insulation. For this purpose, water trees were grown in compression molded disks, obtained from pellets of either thermoplastic (LDPE) or chemically crosslinkable polyethylene provided by Borealis. Two types of pellets of crosslinkable polyethylene were evaluated: one containing only peroxide (XLPE1) and another having, besides peroxide, a tree retarding additive system (TRXLPE). The results obtained indicate that there is no significant difference between the average of water tree lengths in XLPE1 (286 µm) and those in LDPE (269 µm). This is in agreement with the result of a previous study in which water treeing in irradiation crosslinked samples was analysed. On the other hand, the water tree lengths in TRXLPE (122 µm) are much smaller than in LDPE and XLPE1.

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1. Introduction

Crosslinked polyethylene (XLPE) has been extensively used in the last years in underground transmission and distribution cables, replacing LDPE which was previously used for extruded cable insulation. The main reason was that by crosslinking, the thermal and the dimensional stability is improved, without affecting the electrical properties of the polymer. Besides its mechanical resistance and electrical performance, another property that is considered when choosing the insulating material for power cables is its water tree resistance, because in MV cables the main cause of the insulation breakdown is the aging due to water treeing [1]. Does the crosslinking itself play a role in water treeing in polyethylene insulation? This is the question that our study, started four years ago, is trying to answer.

The previous research we performed on irradiation crosslinked samples [8] has led us to the conclusion that polyethylene crosslinking does not create any network able to hinder the migration of water through the polymer under the action of the electric field and, therefore, no consistent influence of the irradiation crosslinking on water tree growth could be observed.

Since the most common technique used today for the cable insulation manufacturing, is not irradiation, but crosslinking by dicumyl peroxide, the latter technique has been widely studied.. It has been shown that this method creates crosslinking by-products which can affect the insulation properties. It has, for example, been shown that acetophenone, which is one of the decomposition by-products of the peroxide used for this reaction, is a water tree inhibitor. In fact, if acetophenone and the other by-products are extracted from XLPE by vacuum heating, the original water tree resistance of XLPE decreases. Experiments performed on two samples of the same base polymer,

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one of them being crosslinked and degassed, could not show any difference between the growth kinetics of water trees in each sample [7]. It was concluded that better water treeing resistance of XLPE was really due to the effects of the reaction by-products and it was assumed that the differences in morphology between XLPE and LDPE did not influence the propagation of water trees. However, the large dispersion of the water tree lengths observed in [7] has led us to wonder if a better accuracy, presently available, could not reveal a certain difference between XLPE and LDPE growth kinetics. Moreover, water tree retardant materials being more and more used to reduce the number and size of water trees in cable insulation [9] it was of interest to include a water tree retardant material in our work and we present here some preliminary results on TRXLPE aimed at clarifying the role of tree retardant additives combined with that of crosslinking in water treeing.

2. Experimental

2.1. Samples

Disks of 0.5 mm thickness and 50 mm diameter were pressmoulded from pellets of polyethylene provided by BOREALIS, in a CARVER press (model 2696) using a pattern with 12 holes of 50 mm diameter and 0.5 mm thickness (Fig. 1). The pellets of LDPE without additives were pressed 5 min at 150°C and 10^5 N and afterwards, the samples were cooled in air at room temperature, while the pellets of crosslinkable polyethylene (both XLPE1 and TRXLPE) were pressed 14 min at 195°C and 10^5 N and then the cooling was made with a rate of 15 °C/min. In order to obtain identical samples, the quantity of pellets used in each hole of the pattern was set by taking into account the hole volume and the density of polyethylene as given by the polyethylene manufacturer. After manufacturing the XLPE1 and TRXLPE samples were degassed in vacuum at 90°C for 72 hours.

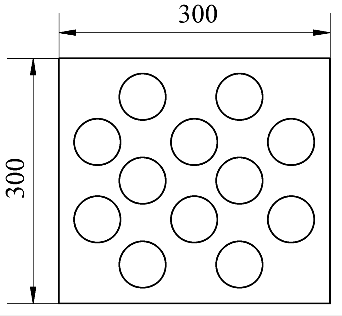

Fig. 1. Pattern used to manufacture the samples.

On one face of each sample, small needle-like defects were created, as initiation sites for water trees, by pressing a sheet of abrasive paper (P240) on one face of the sample, for 2 min at 50 MPa.

2.2. Crosslinking degree

The crosslinking degree of the thermoplastic and chemically crosslinked samples was assessed by gel fraction measurements in accordance with the ASTM D2765 procedure. Thus, samples were exposed to refluxing xylene close to its boiling point, and the extraction was carried out until the insoluble gel reached a constant weight. The extraction time was of at least 96 hours.

2.3. Water trees

Water trees were grown in cells (Figure 2) realized by fixing the sample on a polyethylene tube, using LOCTITE 401 after an adequate surface treatment. The electrolyte was a NaCl solution of concentration c = 0.1 mol/l. Groups of five cells were fixed in a cell-holder and water trees were grown by applying the samples an electric field of 4 kV/mm, 5 kHz, for 25 hours.

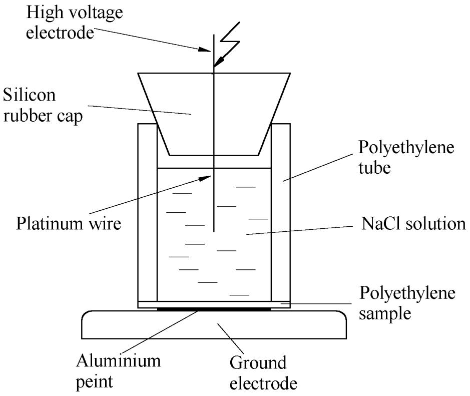

Fig. 2. Cell used to produce water trees.

Then, the samples were dyed in order to facilitate the measurements of water tree lengths. Thus, the samples were detached and introduced in a rhodamine solution at 60 °C where they were maintained for 3 days. Afterwards, three slices of 200 μm thickness were microtomed from each sample (Fig. 3a), and the lengths of all water trees from each slice were measured using the experimental setup shown in Figure 4. The average length L_a for a sample was determined as the average of the water trees lengths L_k measured on the three slices of the sample (Fig. 3b).

Ten samples of each type (LDPE, XLPE1 and TRXLPE) were tested by the procedure described above.

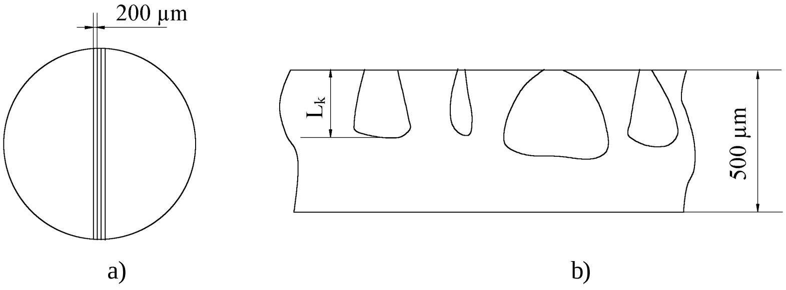

Fig. 3. a) Slices for measuring water trees dimensions; b) Water tree length L_k as measured on a slice.

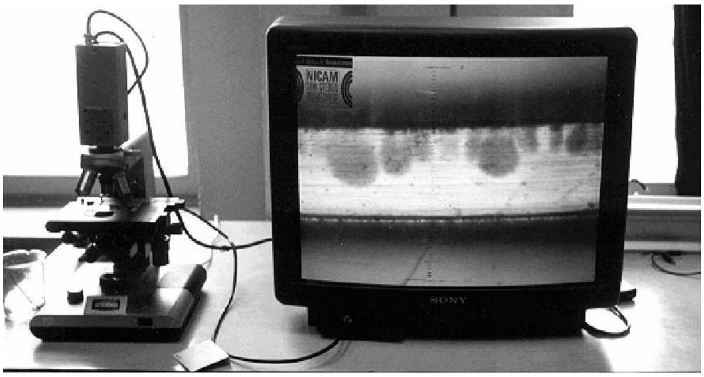

Fig. 4. Setup used to measure water tree lengths.

3. Results and discussion

In Table 1 are presented average lengths of water trees measured on all tested samples and the measured crosslinking degree in LDPE, XLPE1 and TRXLPE.

Table 1.

Samples	Crosslinking degree [%]	Water tree lengths of the ten tested samples [μm]										Average length [μm]
		L_{a1}	L_{a2}	L_{a3}	L_{a4}	L_{a5}	L_{a6}	L_{a7}	L_{a8}	L_{a9}	L_{a10}	L
LDPE	0	281	275	282	283	255	273	259	262	262	260	269
XLPE1	81	281	293	275	279	309	282	283	285	289	283	*286*
TRXLPE	94	118	100	115	108	101	123	152	130	153	122	*122*

Thus, from the results shown in Table 1 it can first be observed that the tree lengths are practically the same in LDPE and in XLPE1 samples. Since the samples had been degassed it can be concluded that the crosslinking itself does not influence water tree growth. This confirms the previous results obtained in other conditions and with a less accuracy. However, it remains to examine the exact role played by the by-products of crosslinking and this aspect will be analyzed in future research. On the other hand, we can notice that the water tree lengths in TRXLPE are much smaller than in LDPE and in XLPE1. This first confirms the reality of the retarding effect of the selected additive, compared with XLPE1 which is the same material but not containing the additive. The material being degassed, it can also be concluded that the retarding effect observed is not related to labile peroxide by-products from the crosslinking reaction, but to the permanence of the tree retardant additive in the crosslinked material. Work is in progress to further study this question.

4. Conclusions

It was shown from water tree growth studies in LDPE and XLPE samples that chemical crosslinking in itself is not a retarding factor for water tree growth. The conclusion is in agreement with results obtained with electron beam crosslinked polyethylene. Work is in progress to examine the role of crosslinking in water treeing retardant materials.

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