Polymer Testing 50 (2016) 235–240

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Short Communication: Test Method

Research on the water blade electrode method for assessing water tree resistance of cross-linked polyethylene

Chengcheng Zhang [a, b, *], Chunyang Li [a], Linlin Nie [a], Ziang Jing [a], Baozhong Han [a, c, **]

[a] Key Laboratory of Engineering Dielectrics and Its Application, Ministry of Education, Harbin University of Science and Technology, Harbin 150080, PR China
[b] Yuancheng Cable Co. Ltd., Yixing 214200, PR China
[c] Shanghai Qifan Wire and Cable Co. Ltd., Shanghai 200008, PR China

ARTICLE INFO

Article history:
Received 18 December 2015
Accepted 25 January 2016
Available online 27 January 2016

Keywords:
XLPE
Water tree
Water blade electrode
Finite element simulation

ABSTRACT

A new water blade electrode method is presented to accelerate water tree initiation and propagation in cross-linked polyethylene (XLPE) insulation, and the validity was verified by a series of experiments. Water tree morphology and length over time were monitored using a polarized light microscope and compared to the results through the conventional water needle electrode method. The influence of electric field distribution along the water electrodes on water tree initiation and morphology was also investigated on the basis of experimental data and finite element simulation. Furthermore, the effect of voltage frequency on water tree initiation was also investigated. It was found that the water blade electrode method could greatly accelerate water tree initiation and propagation and it was more convenient to slice XLPE for observation. The high frequency voltage could more efficiently facilitate water tree initiation and propagation.

1. Introduction

Under the combined effects of moisture and electric field, the initiation and propagation of water trees is one of the main aging phenomena in middle and low voltage cross-linked polyethylene (XLPE) insulated underground power cable [1,2]. Once water trees form, they will gradually transform to electrical trees as the electric field on the edge of water trees continuously concentrates. Electrical trees can lead to breakdown of cable insulation in a short period of time, and result in power supply blackout [3]. The initiation and propagation of water trees shorten the service life of power cable, and become a potential threat to the power supply security of networks. Therefore, the development and application of water tree retardant XLPE (WTR-XLPE) insulation materials have important theoretical and practical significance in improving the quality of cable insulation.

Many routines have been developed to inhibit the initiation and propagation of water trees, and a series of WTR-XLPE insulation materials have been prepared [4–8]. In actual operation, water tree aging of XLPE insulation materials is a very slow process, and may take a couple of years or decades. Therefore, accelerated aging tests are adopted by most of the cable manufacturers and users to assess the performance of WTR-XLPE insulation materials [9]. The most common method is by creating defects using a water needle electrode which can provide local high electric field and water for water tree initiation and directly cultivate water trees. Then, the specimens are sliced and observed using a polarized light microscope for measuring the length of water trees. However, the water needle electrode method has a complicated preparation procedure and the number of initiation positions for water trees in one specimen is limited. At the same time, it is difficult to slice the specimen for observing water trees, and the slicing position easily deviates leading to the dispersion of experimental data. Therefore, it is emphasized as an important subject in the insulation materials and cable industry to search for a fast and accurate method for assessing water tree resistance of XLPE insulation materials.

In this paper, a new water blade electrode method is presented to accelerate the initiation and propagation of water trees based on the original water needle electrode method. It was verified through

* Corresponding author. Key Laboratory of Engineering Dielectrics and Its Application, Ministry of Education, Harbin University of Science and Technology, Harbin 150080, PR China.
** Corresponding author. Key Laboratory of Engineering Dielectrics and Its Application, Ministry of Education, Harbin University of Science and Technology, Harbin 150080, PR China.
E-mail addresses: cczh0111@126.com (C. Zhang), hbzhlj@163.com (B. Han).

http://dx.doi.org/10.1016/j.polymertesting.2016.01.017
0142-9418/

a series of experiments and finite element simulation results of electric field distribution along the water electrode that using the water blade electrode could improve the initiation rate of water trees, facilitate slicing for observing water trees and reduce the dispersion of experimental data. The water blade electrode method can assess water tree resistance of XLPE insulation materials more efficiently and accurately. Water tree initiation and propagation in XLPE and WTR-XLPE insulation materials under different voltage frequencies were also studied using the water blade electrode method.

2. Experimental

2.1. Materials

The low density polyethylene (LDPE, LD200BW) pellets with a density of 0.922 g/cm^3 and a Melt Flow Index (MFI) of 2.0 g/10 min were purchased from Beijing Yanshan Petroleum Co. Ltd., China. Dicumylperoxide (DCP) was obtained from Shanghai Gaoqiao Petroleum Co. Ltd., China. Methylene blue was purchased from Tianjin Zhiyuan Chemical Reagent Co. Ltd., China. Sodium chloride (NaCl) was supplied by Beijing Petsun Chemical Technology Co. Ltd., China. All the above chemicals were used as received without further purification.

2.2. Specimen preparation

LDPE and water-tree-retardant cross-linkable PE were compression moulded under a pressure of 15 MPa at 110 °C and then crosslinked under the same pressure at 175 °C for 30 min to obtain the specimens of size 100 mm × 100 mm × 4 mm.

2.3. Water tree tests

The specimens for water tree tests were divided into two groups for testing with the water blade and water needle electrode methods, respectively. For the water blade electrode method, the specimen shape and the arrangement of cuts are shown in Fig. 1a. Two cuts were made by using a blade perpendicular to the surface, leaving a residual thickness between the blade and the other surface of the specimen of 2 mm. The two cuts acted as the defects in the insulation and would be the starting point of water tree initiation and propagation. For the water needle electrode method, the specimen shape and the arrangement of pinholes are shown in Fig. 1b. Seven pinholes were obtained by using a needle to prick the specimen perpendicular to the surface, and the residual thickness was also 2 mm. After the defects were introduced, the aluminum electrode was deposited on the other surface of the specimen by a vacuum coating system as the grounding electrode.

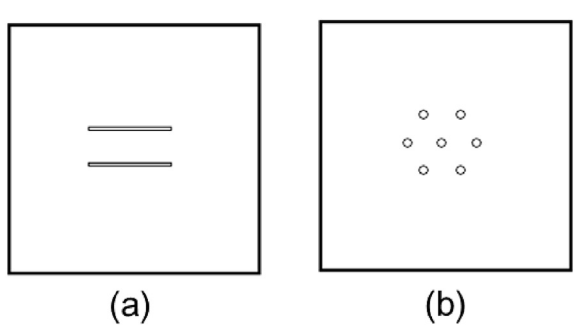

Fig. 1. The schematic diagram of the specimen shape and the arrangement of the defects by applying the (a) water blade electrode and (b) water needle electrode.

Fig. 2 shows the experimental setup for water tree tests. After a PP pipe was glued to the surface of the specimen with defects, a little 1.8 M NaCl water solution was poured into the PP pipe, and then the pipe and the specimen together with the solution were all kept in vacuum oven for 30 min to remove the air in the cuts and pinholes. For water tree tests, an AC voltage of 4 kV with frequency of 50 Hz or 3 kHz was applied to the specimen through a high voltage line immersed in 1.8 M NaCl water solution used as the electrolyte for 1–7 days at room temperature. After a certain time, the specimens were cut into slices with thickness of 180 μm to guarantee the cuts and pinholes in the middle of the slices. After the slices were stained with methylene blue for 4 h, the water tree morphology and length in each slice were observed and recorded by a polarized light microscope. Water tree length was determined by the average length of the longest branch of water trees along the direction of electric field.

3. Results and discussion

The protrusion at the contact surface of the insulating and semiconducting layers in the cables, and the defects such as chemical residues, water droplets, microvoids, etc. in the insulation generally have higher electric field and become water tree inception points. In this paper, the water blade and water needle gaps were adopted to simulate these defects to accelerate the initiation and propagation of water trees to compare and analyze the two experimental methods and estimate water tree resistance of different XLPE insulation materials.

The morphology of water trees in XLPE initiated by the water blade and water needle electrode methods at a voltage of 4 kV and frequency of 3 kHz is shown in Figs. 3 and 4, respectively. The average length of the longest branch of water trees along the direction of the electric field was statistical treated and the plots of the length versus time are given in Fig. 5.

The morphology of water trees in WTR-XLPE initiated by the water blade and water needle electrode methods at a voltage of 4 kV and frequency of 3 kHz is shown in Figs. 6 and 7, respectively. The average length of the longest branch of water trees along the direction of the electric field was statistical treated and the plots of the length versus time are given in Fig. 8.

As seen from the above results, when the water blade electrode method was applied, a fan shaped water tree formed at the tip of cuts and it propagated radially down the tip of cuts. However, when the water needle electrode method was applied, a dense water tree developed at the tip of pinholes and surrounding the water

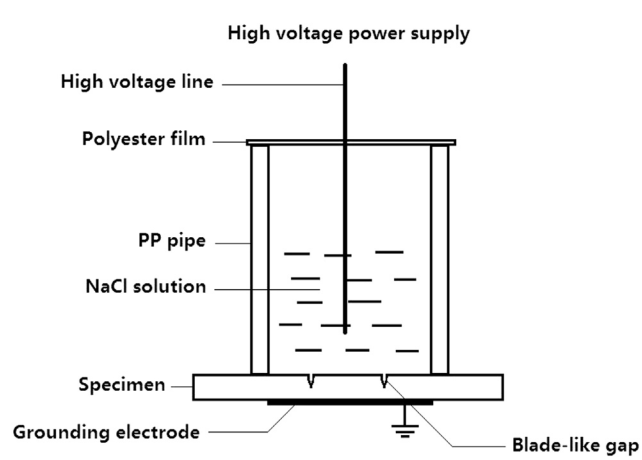

Fig. 2. The schematic diagram of the experimental setup for water tree tests.