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The impact of electrical treeing on a cable-embedded fibre

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ABSTRACT

The development of electrical trees near to a cable-embedded fibre is investigated using composite samples with a pin to plane configuration. The tree growth under high electric field is monitored using advanced optical system, equipped with a high-resolution camera and microscope. The slow stressing of polyester material around the fibre surface is assessed as a function of electrical tree development. The tree growth is evaluated by observing the expansion and enlargement of branches in the horizontal and vertical directions. The impact of electrical trees on the fibre optic cables is translated into a distortion of the fibre surface and into irregularities of the surrounding treed area. The shapes and areas of deformed fibre are used as criteria for characterizing cable conditions exposed to high field. A deformation factor is introduced to describe these irregularities in the embedded fibre. Although the focus of the present paper is on the treed region, located between the pin tip and the fibre surface, the conditions of the fibre-to-ground region are also examined.

1. Introduction

The "treeing" phenomenon in dielectric material is the term that has been given to a type of electrical deterioration, appearing as a tree-like path, through the wall of insulation [1]. For transmission and distribution cables, electrical treeing is considered a serious mechanism for breakdown of such cables [2–4]. The knowledge in electrical treeing was gained from the extensive studies, based on classical needle–plane configuration. These studies were conducted by several researchers in the last three decades [5–8]. According to these studies, the main factors affecting the tree inception and growth are the tip–plane distance, the needle-radius, voltage level, frequency, material structure and temperature.

The significance of the tree role in the cable breakdown was the main reason for the presence of various models of electrical tree growth. There are many works investigating electrical treeing in single dielectric materials, whereas, the studies characterizing such trees in composites are few. Some of these studies were interested in determining the tree propagation rates in polymers with barriers of different materials, whereas, others have focused on the retardation capability of such barriers. However, for fibres embedded within power cables the interest is mainly concentrated on the performance of such fibres under high electric fields [9].

Although there are common characteristics of tree propagation in the barrier and fibre regions, there are several distinguishing features of these propagations attributed to the difference between fibre and barrier configurations. Firstly, the barrier dimension is significantly larger than that of fibres. Therefore, the experiments and numerical simulations, which were conducted for tree propagation in barrier region, have shown that the presence of such barriers can significantly delay the breakdown. In case of fibre, the time to breakdown is expected to be shorter. Secondly, the fibres are made of materials other than that of barriers [10–14], which cause a significant difference in response to treeing. Thirdly, the tree interaction with the barrier is different from that with the fibre. The small size of the latter encourages the tree to bypass it, whereas, in the case of large barriers the tree is either spreading under the barrier or attempting to penetrate it [2]. Nevertheless, the electrical tree will not be able to penetrate the barrier or fibre unless the material of such obstacles has been impaired by electrical or mechanical stressing.

Based on these facts, the target of the present study is to investigate the treeing characteristics in the vicinity of fibres embedded in polyester resin. This includes the changes in the growth rate and the dimensions of electrical tree approaching the fibre surface. In parallel with this assessment, the state of the treed region will be monitored in regular time intervals.

2. Experimental setup

For all experiments, conducted in the present work, the unsaturated clear casting polyester resin of class C was used. This material is one of the important thermosetting resins, which is characterized by good electrical properties and good resistance to heat, mechanical impact and flame. The transparent feature of this resin facilitates the picturing process of tree images. Therefore, a

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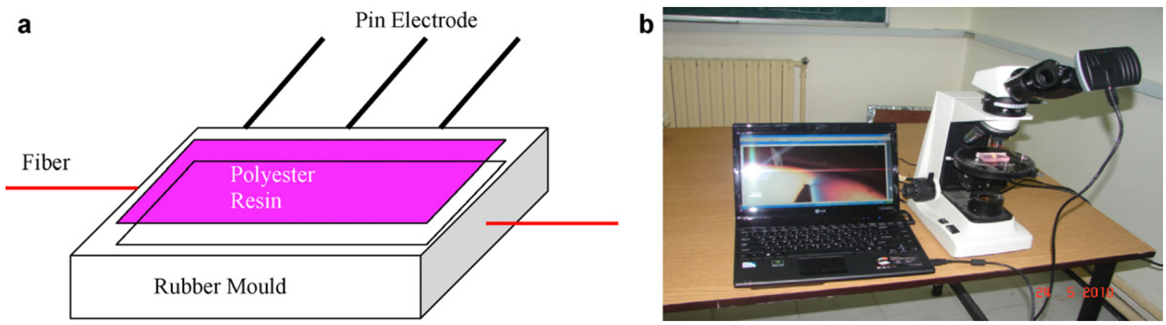

Fig. 1. Specimen fabrication (a) and optical system (b).

number of polyester slabs were cast in order to be used for treeing tests. To produce a pin to plane configuration, a steel needle electrode of 1.0 mm in diameter and 10 μm tip radius was inserted vertically inside the specimen during the moulding process, whereas, the grounding lead is connected to the sample via a thin sheet of conducting foil. A single fibre is also inserted during casting as shown in Fig. 1a. The vertical distance between the tip of the pin electrode and the bottom ground plate is 1 mm. The specimen was subjected to an ac voltage of 10 kV_{rms}, 50 Hz. The specimens were taken out of the test cell every 1 h and checked under the microscope, which has high-resolution and several magnification levels. To take high quality pictures of the tree images, a special digital camera was fitted on the microscope as shown in Fig. 1b. The camera has a high-resolution chip (1.3 M) attached to the microscope. Moreover, the computer connection of this camera allows obtaining real-time and non-compressing video data, in addition to the capability of direct capturing of images. The schematic diagram of the optical system was explained in details in previous works [15,16]. The present tests were conducted under ambient conditions with a room temperature of 25 ± 3 °C and relative humidity of 45 ± 5%. A 25 kV testing transformer connected to a remote control panel was used in this test.

The approach of using fibre optic cables, embedded in power cables, was known since 1990s. Several types of high voltage and extra high voltage cables were manufactured with optical fibre integration and this was clearly discussed in the literature in the last two decades [17]. One of common applications of this system is the submarine links, which include optical fibres as part of power cables. Practically, such cables are exposed to high voltage stresses, which can cause and develop electrical treeing. This effect is aggravated when there is an internal mechanical defect in the form of edges, protrusions, cracks, and others. If the electrical tree, growing within the cable insulation, reaches the surface of embedded fibre, it will degrade it. Since the transmission quality of optical fibre is a function of its state, it is necessary to keep the signal route free of damage or deformation. Therefore, this work is an attempt to experimentally simulate and reproduce a practical case of fibre degradation using polyester samples with embedded fibre.

3. Results

The use of microscope for electrical tree inspection is an effective approach for assessing the conditions of transparent insulating materials. The examined composite specimens are pictured before applying the voltage and before the initiation of the tree, which took 1 h in average. Fig. 2 illustrates the pictures of pin tip and the fibre embedded in the resin. It is clear that the area between the tip and the fibre is free from any defects or signs of stress. However, when a voltage of 10 kV is applied for 2 h and longer, the region located between the pin tip and the fibre surface is affected by the stress caused by the electric field. Fig. 3 shows the primary indices of degradation caused by such stresses, whereas, Fig. 4 illustrates an image of heavily stressed region after 2 h and 30 min. The deep focus on this image illustrates several thin branches of electrical trees grown in this area. The average thickness of branches of these trees is about 10 μm. This phase is considered an initial stage of electrical tree, growing from the tip of pin electrode as shown in Fig. 5. Four hours were needed to achieve this level of tree growth. The response of treed region and fibre surface to the stress appears as a multi-stage deformation. The image of electrical tree, shown in Fig. 5, does not illustrate all sizes of branches grown from the pin tip. Some of these branches are 10 times smaller than others, so they do not clearly appear in the shown image. However, the picture was magnified by 2–3 times, to clearly show the tree when it approaches the fibre surface. Fig. 6 shows a tree image after 8 h of growth, in which the branches are further grown towards the fibre surface. This advanced stage of tree development is characterized by long, wide and dark-coloured branches. The width of the

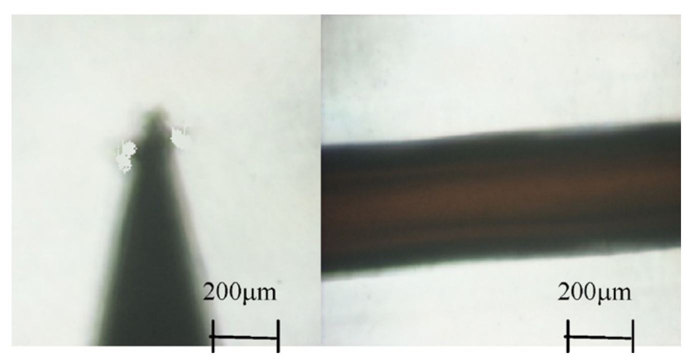

Fig. 2. Images of resin-embedded pin and fibre.

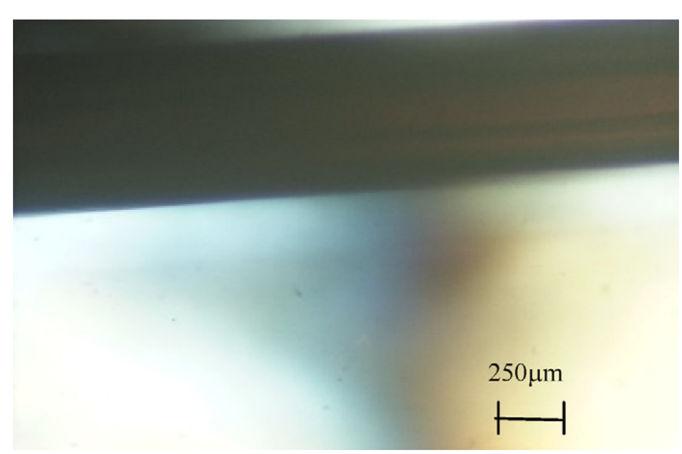

Fig. 3. Image of stressed region between pin tip and fibre after 2 h of voltage application.