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Tracking, Erosion and Morphological Study of Heat Shrink Anti Tracking Tubes

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Abstract

Components of Medium Voltage (MV) cable network are very much vulnerable under operational stresses and ageing. Heat Shrinkable Anti-Tracking Tube (HSATT), an integral part of the Joints and terminations of the MV cable network system is used to cover and safeguard the power cable joints. In cable system joint and termination are the weakest but the critical part and fail easily under stress. The most threatening source of HSATT failure is electrical tracking. Electrical tracking develops when a conducting path across the HSATT formed under electric stress due to surface discharge. Arcs created from this surface discharge phenomenon burn the HSATT and create carbonized tracks in the long run. This paper reports the electrical tracking performance of three commercially available HSATT samples. Crosslinked polyethylene (XLPE) is the key ingredient for heat shrinkable materials. Electrical tracking using the inclined-plane tracking (IPT) method develops from surface discharge activity followed by erosion under wet and contaminated conditions. So, the material under IPT test faced electrical, environmental and thermal stresses. Among these three HSATT samples two samples failed to withstand these three dimensional stress factors. Dielectric breakdown strength and volume resistance tests were carried out to cross examine the IPT results and the results are identical. The morphology has been studied to understand the failure mechanism of HSATT samples. A morphological model is presented to scrutinize the IPT test failure mechanism and the rate of erosion propagation in the HSATT samples.

Keywords: Dielectric Breakdown, Heat Shrinkable Anti-Tracking Tube, Inclined-Plane Tracking Strength, Morphology

1. Introduction

A huge ratio of MV cable failures in current years involve in problems with joints and terminations components. Heat shrinkable type is one of the most popular jointing systems which is used to maintain the continuity of cable. Polyethylene is the widely used polymer in the production of heat-shrinkable materials. The polymer is semicrystalline in its normal state. This semi crystalline material is crosslinked and become thermoset material by high energy radiation or by chemical to achieve a 3-dimensional network structure which can meet the desire properties during service. This cross linked Polyethylene is the main component of HSATT compounding because it can store large deformations that can be recovered on application of heat[1]. But, these materials face a problem with tracking and erosion susceptibility under outdoor high voltage application. They cannot maintain surface hydrophobicity during service and suffer from environmental and electrical aging stresses that may cause their performance to deteriorate. It is well known that tracking has been the most common cause of insulation failure. Therefore, for better understanding of HSATT, the electrical tracking test appears to be a useful tool to check the surface degradation due to environmental agents. Electrical tracking develops on the surface discharge and is influenced under wet and contaminated (polluted) conditions. Finally, the insulation breaks down when the carbonized tracks bridge the distance between the electrodes. In addition, formation and structure of the XLPE composite also contribute to the Tracking, erosion and other dielectric properties of HSATT materials. Dicumyl peroxide (DCP) is the main crosslinking agent for HSATT. It is significant to gain knowledge to correlate the formation and structure of HSATT with the electrical properties for superior quality products.

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With this objective, this paper investigated the electrical tracking, erosion, dielectric breakdown and DC resistance performance on three different commercially available HSATT materials and these properties are analysed along with their morphological structure.

2. Materials

Three commercially available Heat Shrinkable Anti-Tracking Tubes were selected for this study. The tubular specimens were thermally recovered fully at 150±3 °C for a duration of 20 minutes to plaque specimens and designated as HSATT1, HSATT2 and HSATT3.

3. Experimental

3.1 Tracking and Erosion Test

Tracking and erosion test was conducted based on the inclined plane tracking method of ASTM D2303-20 and Energy Networks Association Technical Specification 09-13, Issue 1: 1981, and the schematic diagram shown in Figure 1. The sample was mounted with the flat test surface on the underside, at an angle of 45° from the horizontal with the stainless steel electrodes 50 mm apart. The sample was wet-contaminated with an electrolyte that contained 0.1% by mass of ammonium chloride with Triton X-100 non-ionic wetting agent. A peristaltic pump was used to continuously deliver the electrolyte at a flow-rate of 0.15 ml/min for 2.5, 2.75 kV and 0.30 ml/min for 3.00, 3.25 kV. The test is conducted on four steps. First step: 2.50kV, 0.15ml/min flow rate, duration 1 hour, Second step: 2.75kV, 0.15ml/min, flow rate, duration 1 hour, Third step: 3.00kV, 0.30ml/min flow rate, duration 1 hour and Last (fourth) step: 3.25kV, 0.30ml/min flow rate, duration 20 min. The electrical tracking performance was carried out by the length of carbon track and erosion dimension for this study.

3.2 Dielectric Strength

Break down voltage test was carried out on fully recovered tube specimens on Aluminium mandrel as per Energy Networks Association Technical Specification 09-13, Issue 1: 1981 in transformer oil at ambient temperature using a high voltage source (100kV Test Transformer, Peak/RMS Voltmeter) and rate of rise of voltage was 2kV/sec. Average of three results was reported.

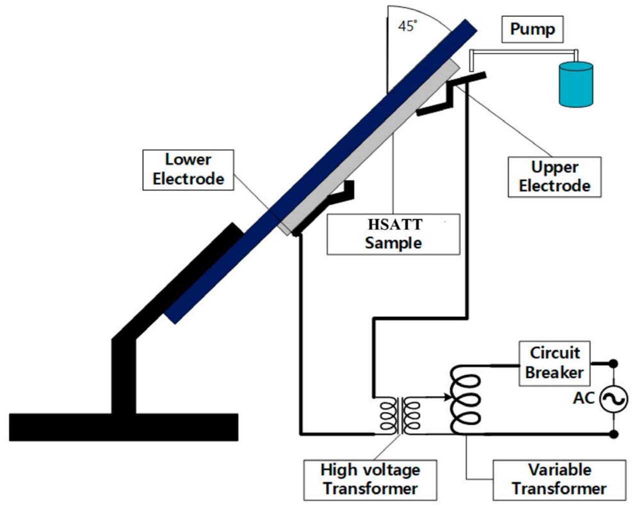

Figure 1. Diagram of tracking and erosion test set up.

3.3 Volume Resistivity

A Sefelec Megohm Meter, model M 1500P was used to measure volume resistance of HSATT plaque specimens. 500V DC voltage was applied for 60 seconds and Volume Resistivity was calculated as per ASTM D257-14 on 95 mm length, 80 mm width film at ambient temperature. Average of five results was reported.

3.4 Morphological Analysis

A morphological study on the surface microstructure of HSATT samples was carried out using a Scanning Electron Microscope (SEM) after the tracking test.

4. Results

4.1 Tracking and Erosion Test

Each HSATT sample presented different strength under Tracking and erosion test. In presence of contamination solution and applied voltage, arcing initiated on the surface of the specimen after a certain time period for each HSATT sample. The carbonized tracking paths were developed from bottom electrode to top electrode for HSATT1 and HSATT2. Table 1 and 2 show the tracking and erosion properties of HSATT1 and HSATT2 samples. Once the leakage current surpass threshold limit, flaming and ignition were started for HSATT1 and HSATT2 in third and fourth step respectively. HSATT1 could not withstand the third step. Whereas, HSATT2 failed on the fourth step. Propagation of tracking and erosion was very speedy for all specimens of HSATT2. As per the test outcomes, the test voltage clearly affected the time to failure of surface resistance of the HSATT2 specimens. However, the third sample showed no tracking and erosion at all. Literatures revealed that the ATH filler plays an important role in improving surface tracking performance by allowing an endothermic dehydration that decreases the amount of thermal decomposition products[2]. Though Piah *et al.* 2005, observed that only LLDPE, could provide high electrical tracking resistance[3]. Therefore, an optimize amounts of base polymer and filler is essential during compounding. The failure of HSATT1 and HSATT2 can also happen due to use of substandard quality materials.

Table 1. Tracking and erosion test results of HSATT1

Specimen- 1 First and Second steps Third step	No tracking and erosion Tracking initiated after 50 mins with flaming and progressed quickly and crossed 25 mm mark within 10 mins. Erosion: 26mm × 6.12mm × 0.9mm
Specimen- 2 First and Second steps Third step	No tracking and erosion Tracking initiated after 34 mins with flaming and progressed quickly and crossed 25 mm mark within 17 mins. Erosion: 27.2 mm × 5.87mm × 1.32mm
Specimen- 3 Third step	Tracking initiated after 43 mins with flaming and progressed quickly and crossed 25 mm mark within 16 mins. Erosion: 25.6 mm × 5.14 m × 1.13mm
Specimen- 4 Third step	Tracking initiated after 15 mins with flaming and progressed quickly and crossed 25 mm mark within 20 mins with severe flaming Erosion: 25.2 mm × 4.27mm × 0.87mm
Specimen- 5 Third step	Tracking initiated after 45 mins with flaming and progressed quickly and crossed 25 mm mark within 12 mins with severe flaming Erosion: 25.82 mm × 4.90mm × 1.87mm

Table 2. Tracking and erosion test results of HSATT2

Specimen- 1 Third step Fourth step	Tracking and erosion initiated Tracking initiated after 5 mins with flaming and progressed quickly and crossed 25 mm mark within 10 mins. Erosion: 16.10 mm × 25.12mm × 3mm
Specimen- 2 Third step Fourth step	Tracking and erosion initiated Tracking initiated after 7 mins with flaming and progressed quickly and crossed 25 mm mark within 17 minutes. Erosion: 10.95 mm × 26.65 mm × 3 mm
Specimen- 3 Third step Fourth step	Tracking and erosion initiated Tracking initiated after 4 mins with flaming and progressed quickly and crossed 25 mm mark within 16 minutes. Erosion: 19.01 mm × 19.73 mm × 2.63 mm
Specimen- 4 Third step Fourth step	Tracking and erosion initiated Tracking initiated after 5 mins with flaming and progressed quickly and crossed 25 mm mark within 20 minutes with severe flaming. Erosion: 19.86 mm × 18.72 mm × 3.26 mm
Specimen- 5 Third step Fourth step	Tracking and erosion initiated Tracking initiated after 8 mins with flaming and progressed quickly and crossed 25 mm mark within 12 minutes with severe flaming Erosion: 15.10 mm × 22.64 mm × 2.80 mm

4.2 Dielectric Strength and Volume Resistivity

The purpose of the HSATT sample is to offer necessary dielectric strength to the joint and termination part of the cable and to effective transmission of heat out from the cable. Table 3 revealed noticeable reduction in Dielectric Strength and Volume Resistivity were found for HSATT1 and HSATT2 in comparison with HSATT3. The electrical properties of HSATT depend on degree of crystallinity and morphology[3] of the base polymer i.e., XLPE. The properties of other ingredients used in HSATT components are also important factors in the durability of joint and termination part of the cable.

Test	HSATT1	HSATT2	HSATT3
Dielectric Strength (kV/mm)	11.25	13.17	16.82
Volume Resistivity (Ω-m)	1.36×10^{11}	7.80×10^{11}	3.34×10^{12}

4.3 SEM Study

SEM photomicrographs of the eroded portion of HSATT1 and HSATT2 are shown in Figure 2 (a) and (b). The tested part of HSATT3 is represented in Figure 3. From the micrographs analysis, it can be seen that the area of the tracking path and erosion for HSATT1 are greater than HSATT2. HSATT1 specimen 1 showed maximum erosion. For HSATT1 sample as it failed to withstand 3kV and due to poor crosslinging or degree of crystallinity in the material, base polymer melted and came out from the slab under electric stress as shown in Figure 2(a). Because of slightly better degree of crystallinity/ compactness

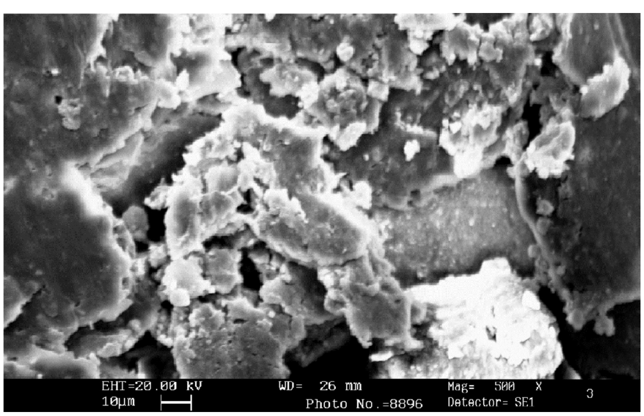

Figure 2 (a). SEM photomicrographs of the eroded portion of HSATT1.

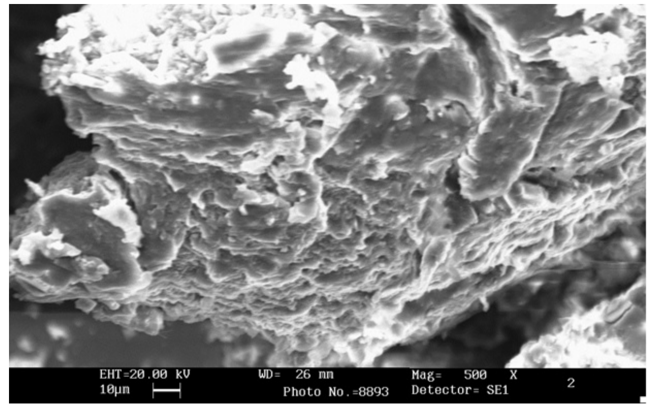

Figure 2 (b). SEM photomicrographs of the eroded portion of HSATT2.

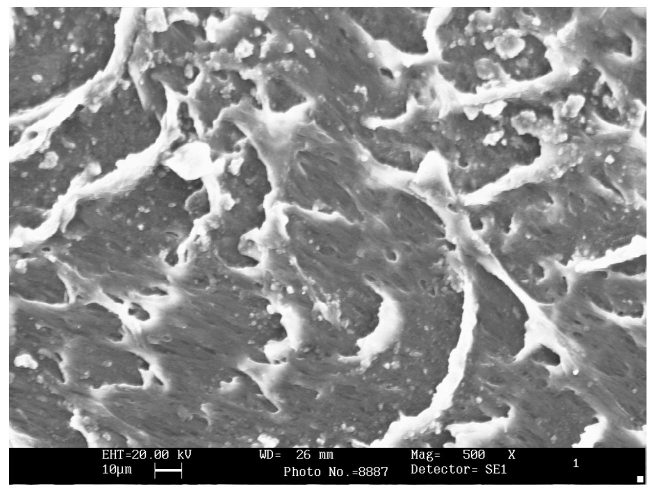

Figure 3. SEM photomicrographs of the eroded portion of HSATT3.

erosion is comparatively less in HSATT2. Microghaph of IPT tested part of HSATT3 sowed no erosion only contaminant flow track was visible under 500× SEM analysis.

5. Conclusion

The data presented in this paper reflect the existing status of the quality of commercial HSATT samples. Tracking and erosion at the surface of joint and termination damage the insulation covering as a result service reliability of the total MV cable system hampers. It was validated that inclined-plane tracking, dielectric strength, volume resistivity and SEM were really helpful to monitoring the quality of commercial HSATT samples. The inclined-plane tracking is mainly dependent on the degree of crystallinity and crosslink density of HSATT samples. A good correlation was found among inclined-plane tracking, dielectric strength, volume resistivity and SEM results.

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7. References

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