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LIGHTNING IMPULSE AGEING OF HV CABLE INSULATION

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Abstract: Lightning impulses can lead to accelerated ageing of extruded cables. Electrical behaviour of a dielectric material when experiencing a lightning impulse is different to that for DC or power frequency applied voltages. Pre-designed shaped HDPE material samples have been manufactured using a mould tool. The samples then have been electrically aged using an impulse generator. A real-time software based monitoring tool has been designed to control the impulse wave-shape and process the measurement data. Sets of identical lightning impulses were applied to samples and this was then followed by ramped AC breakdown tests. The obtained results were analyzed using Weibull distribution to identify any differences in lifetime between aged and unaged samples. Measurements of dielectric loss and space charge were also undertaken to identify the impulse ageing mechanism.

1. INTRODUCTION

Several publications have considered the role of impulse voltages in the ageing processes of polymeric materials. Impulse breakdown strength with the application of a constant DC voltage [1-2] does not directly clarify the effect of the impulse voltage on the ageing process but suggests that there is an influence of impulse polarity on the electric field strength of the material. In this case the main mechanism for the ageing process is space charge accumulation in the sample by the DC constant voltage. However, the situation may be different when a lot of impulses are applied without a constant DC offset voltage. Due to the short on-time and the high magnitude of an impulse, the space charge may not significantly accumulate within the sample. This has been supported by the work of S. Boev, where homocharges were injected into LDPE and XLPE under DC voltages but not under impulses with different parameters [3]. The effect of various impulse types on material life expectancy was observed. The application of repetitive surges or thumper surges reduces the life time of an insulation material [4-5]. Non-standard lightning impulses are also reported to shorten the life expectancy of cable insulation, but the lightning impulse magnitude does not significantly affect the failure rate [5]. The effect of switching impulses was also obtained for EPR and XLPE, providing a sufficient number of impulses were applied [6]. This paper shows the breakdown behaviour of HDPE after the application of a large number of standard lightning impulses. The dielectric relaxation measurements show that the aged samples are lossier than unaged ones and space charge measurements show that the charge profile behaviour changes after the ageing process. All of the above results confirm that after lightning impulse ageing, the electric field strength of the material is weakened, the material becomes more conductive and space charge injection is more effective.

2. SAMPLE PREPARATION AND AGEING PROCESS

2.1. Sample preparation

HDPE with melt flow index of 2.2g/10min was used because it has similar thermal properties compared to XLPE. HDPE pellets were moulded using a hot press method. A final sample has the shape that looks like a bottle cap (Figure 1).

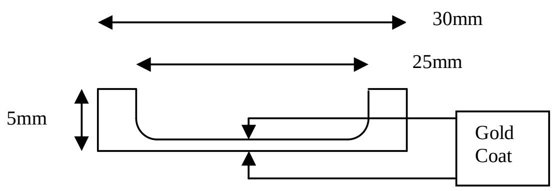

Figure 1: Sample geometry

The inner surface of the sample has a Rogowski profile while the bottom is flat. Top and bottom surfaces are gold coated to create a better contact between the sample and electrode. The thick rim of sample prevents flashover during the ageing experiment. The sample thickness is 190-200 μm.

2.2. Ageing process

Samples were aged using a lightning impulse generator in the Tony Davies High Voltage Laboratory. Five to seven samples were aged at the same time using a multi-mushroom-electrode arrangement. Both negative and positive lightning impulses can be used to age samples. A series of 3000 lightning impulses with front time of 1.2 μs and 40 μs tail time were applied. The peak electric field was 85 kV/mm. Samples were then put into a silicone oil tank within a Faraday cage. Samples after ageing were used in one of the following experiments: ramp breakdown measurements, dielectric loss measurements and space charge measurements.

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3. EFFECT OF LIGHTNING IMPULSE ON BREAKDOWN STRENGTH OF THE MATERIAL

After the lightning impulse ageing process, AC ramp breakdown tests were performed. According to results from previous experiment [7], after the application of 3000 lightning impulses, the electric field strength of HDPE is significantly decreased (Figure 2). The impulse polarities have a minor effect on the ageing process as the 90% confident limits of positive and negative impulse aged samples overlap.

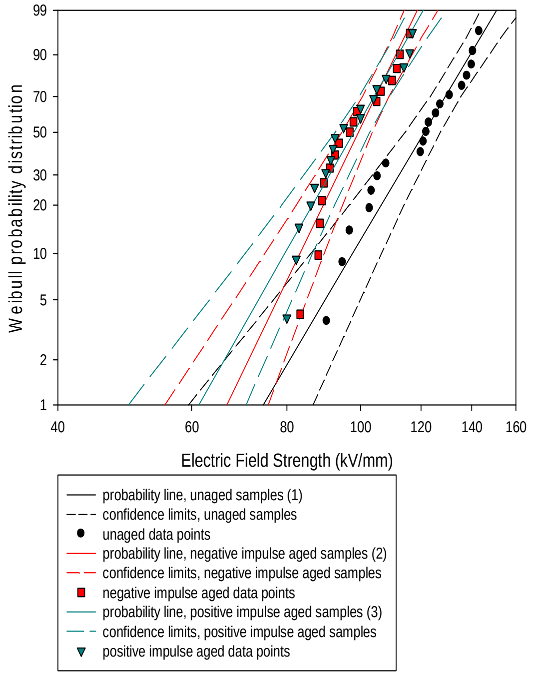

Figure 2: Weibull distribution of electric field strength of HDPE

4. DIELECTRIC RELAXATION MEASUREMENTS

The dielectric relaxation measurements were also taken to compare the dielectric loss between aged and normal samples [7]. The results are shown in Figure 3. Aged samples seem lossier than unaged coated samples. The dielectric loss of an aged sample is reduced after 24 hours. By analyzing the real part of the relative permittivity (Figure 4) and the slope of the relative permittivity tan delta (Figure 3), dielectric loss in aged coated sample increases mainly due to losses in the conduction process. Over time, the real part of relative permittivity of aged samples return to the value of the normal coated sample suggesting that there are surface charges or space charges near the surface after impulse ageing process which may dissipate rapidly over time.

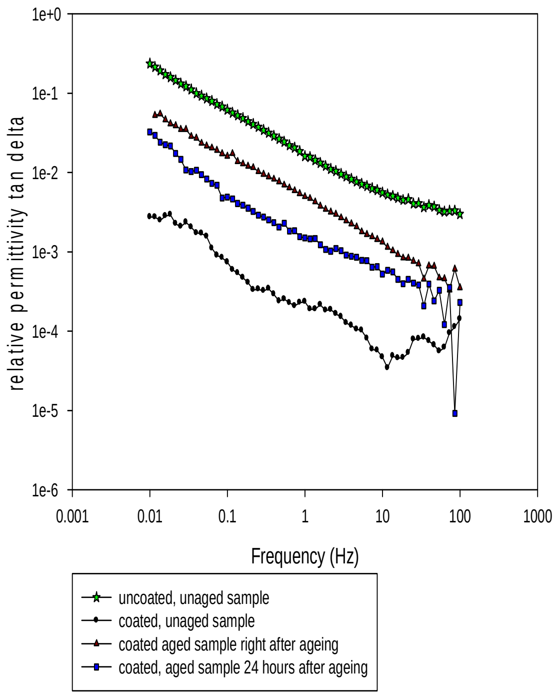

Figure 3: Dielectric loss measurement

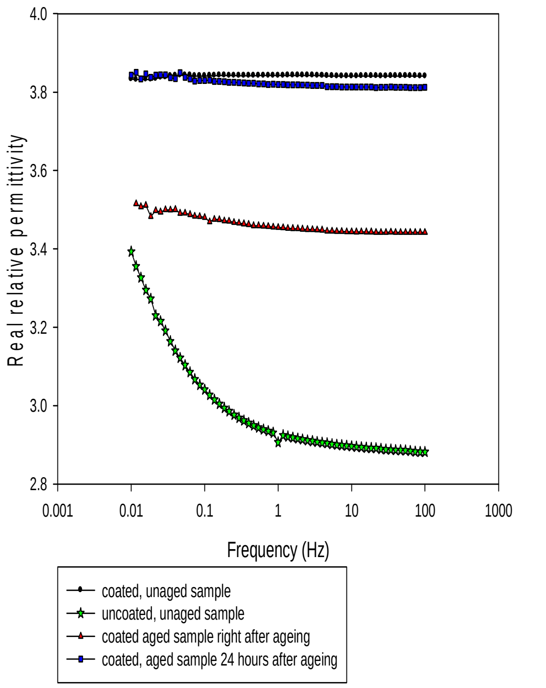

Figure 4: Real relative permittivity over frequency range

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5. SPACE CHARGE MEASUREMENTS

Measurements of space charge accumulation in samples were undertaken using the pulsed electro-acoustic (PEA) method [8]. Figure 5 shows the schematic diagram of the PEA method. The sample was stressed using a DC voltage. When an electrical pulse is applied parallel to the circuit, it produces acoustic waves at charge layers. These acoustic signals are captured by a piezoelectric transducer. This method provides the spatial charge profile within the sample.

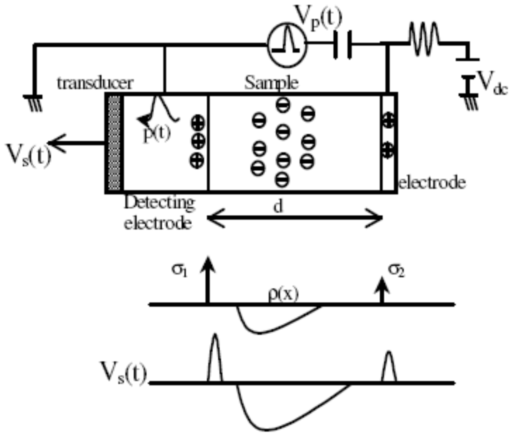

Figure 5: Schematic diagram of PEA method [9]

In order to prevent flashovers during PEA measurements, the samples were not coated. The normal cap-shaped samples were aged using 3000 positive lightning impulses, with 1.2 µs front-time, 40 µs tail time and peak electric field across the sample is approximately 85 kV/mm before the rim was cut out.

The fresh sample was calibrated in the normal way with the voltage applied of 2 kV before the measurements were taken. However, as the aged samples may contain surface or trapped charge, a two step calibration method [9] had to be taken so that the charge profile of the aged samples can be estimated. The samples were stressed with fairly low DC fields of 34 kV/mm. The observation of charge accumulation was taken over a period of 60 minutes. The charge decay measurement (DC voltage is switched off) was not taken because only charge injection is of interest. However, to clarify that deep or shallow traps were created, this measurement will be undertaken in the future experiments.

Figures 6-8 show the charge build up within samples under a constant electric field. In Figure 6 the charge profile is nearly unchanged after 60 minutes. There was almost no charge injection into the sample. In contrast, homocharges were injected very effectively at the cathode in cases of aged samples. The charges were injected near the sample surface and seem to saturate after 10 minutes in present of an applied filed. Effective charge injection only at the cathode suggests that there is an effect due to applied impulse polarity. Charge at the surface of a sample immediately after ageing is higher than the unaged sample and the aged sample after 24 hours. From these results, a conclusion can be drawn that the charges injected into the sample during the impulse ageing process are not significant because they are just charge near the surface and diffuse quite easily. The main reason for a reduction in breakdown strength is more effective charge injection after the ageing process.

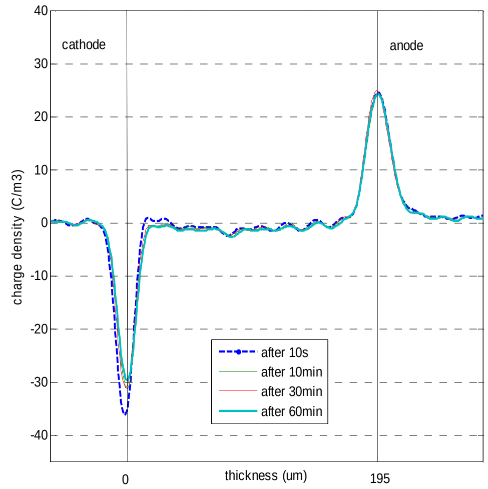

Figure 6: Space charge accumulation of normal sample over 60 minutes

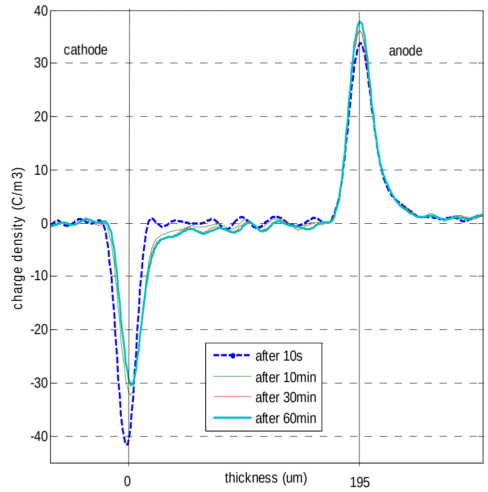

Figure 7: Space charge accumulation of aged sample over 60 minutes

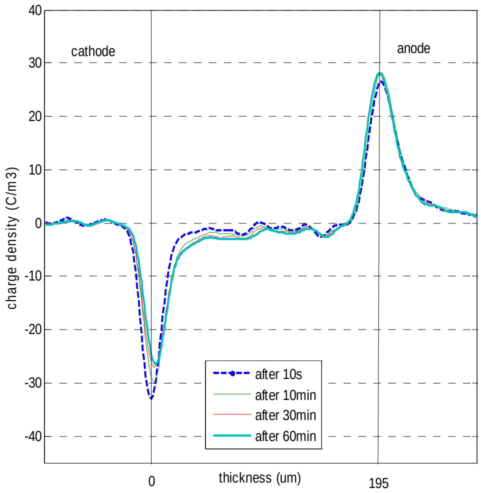

Figure 8: Space charge accumulation of aged sample after 24 hours over 60 minutes

6. CONCLUSION

The breakdown strength is reduced significantly for a sample which experiences a lot of lightning impulses. Dielectric loss and space charge measurements show that insulation material after lightning impulse ageing becomes more conductive, lossier and absorbs charges more effectively. Experiments using more lightning impulse parameter variations should be undertaken to further develop an understanding of lightning impulse ageing mechanisms.

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