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Effect of Barrier Angle on Tree Growth in Solid Insulation

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Abstract

In this research work the effect of barrier angle on tree resistance has been revealed in clear polyester resin. The work to be described studies the possible effect with angular displacement might have the progress of trees in the presence of barrier. The barriers were cast at 0^0, 45^0 and 90^0 with respect to axis of symmetry of the field. The barrier selected for this study were glass and Melinex and PTFE castled in clear polyester resin C. The resin C was selected due to its transparent properties so optical observation and photographic record is possible. The selection of the materials was based on their work of adhesion. These materials were employed in a clear polyester resin thus making a barrier. The specimens, whatever the type (angle0^0, 45^0 and 90^0) were tested in batches of 20 to establish their life time. This was measured in term of number of cycle to breakdown. Hypodermic needle was used as H.V electrode and 28kV A.C was the test voltage. The separation between electrodes is 2mm. The result shows that barriers offer higher resistance when disposed at 90^0 with respect to field.

1. Introduction

Electrical trees have been considered to be, in their early stage of development, the result of mechanical shock waves caused by local intrinsic breakdown of the insulating materials.[1,2]. The same has been confirmed by Hiroaka .V [7]. It follows from this, and has been proven by the results and that of the Auckland [3], that the strain surrounding a barrier effects the progress of the trees as the barrier is approached. Like wise, the strength of the adhesive bound between barrier and surrounding resin also effects the ways in which channels progress in the presence of the barrier [4]. Trees tend to grow in the direction of the applied field. The work done so far has been concerned with the interaction between barriers. The particles, films or fabrics were laying perpendicular to the axis of symmetry of the field. In practice barrier rarely disposed at right angle to the applied field. Thus the shock waves which produce the trees may impinge upon a barrier at many angles with respect to the interface between barrier and surrounding matrix as shown in figure 1.

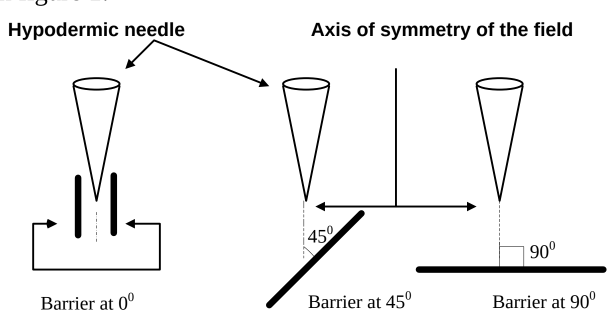

Fig. 1: Disposition of barrier

It has been shown by [5, 6] that stain effects the growth of electrical trees. The barrier disposed at different angle produces different pattern of strain. The work to be described studies the possible effects which angle might have on the progress of trees in the presence of barriers.

2. Materials

The materials used in this investigation were thermosetting polyester resin as matrix, glass of 1mm thickness, PTFE and Melinex as barriers. The criteria of selection of these materials was, as indicated above, based of their work of adhesion with polyester resin. Glass has high work of adhesion, Melinex has medium one while PTFE has low work of adhesion with resin as shown in Table 1.

Table 1

Materials	Y1= mj-m^{-2}	Kc= KN-m-3/2	W_A mJ-m^{-2}	T_c C^0
Glass	560	400	303.5	827
PTFE	11.1	850	42.67	327
Melinex (PET)	43.9	1800	84.85	255

Matrix: Polyester resin Surface energy Y_2 =41mj-m^{-2}

Y Surface energy
W_A= Work of adhesion
Kc = Fracture toughness
Tc = Melting point

The resin was supplied by Scott Bader and is known as clear casting resin C. This resin was chosen because of its ease of handling, rapid curing, good physical and electrical properties, dimensional stability and optical quality.

3. Specimen manufacture:

The specimens were made from resin containing 1% hardener by volume with a thin layer of particles lying between point and plane electrodes. Hypodermic needles were used as point electrode because they are sharp enough to support tree growth, cheap reproducible and readily available. The specimens were cast in strips in a silicone mould supported in a steel frame as shown in figure 2. The walls of the mould were lined on the inside with Melinex which ensured that the sides of the finished product had flat polished surfaces facilitating optical observation.

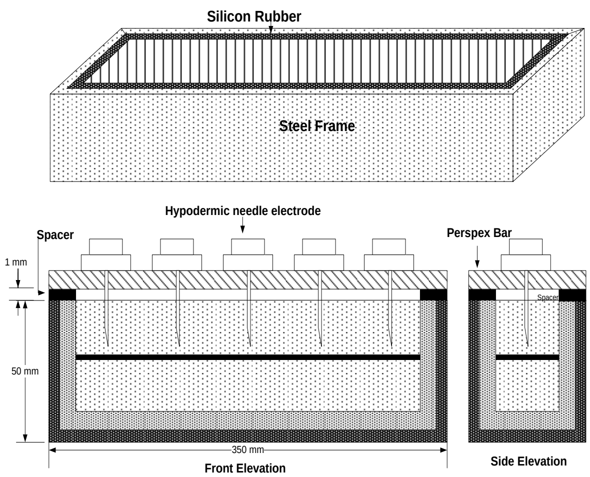

Fig. 2: Specimen manufacture method

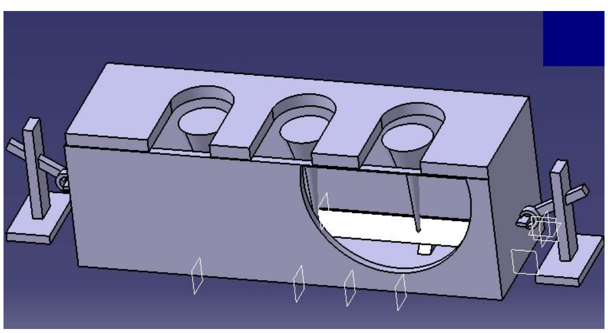

Fig. 3: Specimen manufacture method when barrier disposed at 45^0

Consider first the production of the specimens containing glass containing barrier at zero degree with respect to the axis of symmetry of the field between the electrode. Basically Persrpex strip cut at required angle and then barrier placed and held firmly with perpex piece as shown in figure 3.Hypodermic needles were used as point electrode because they are sharp enough to support tree growth, cheep reproducible and readily available. High voltage 28kV A.C, 50Hz was applied in the form of burst through counter which counts the number of cycles applied to the specimen.

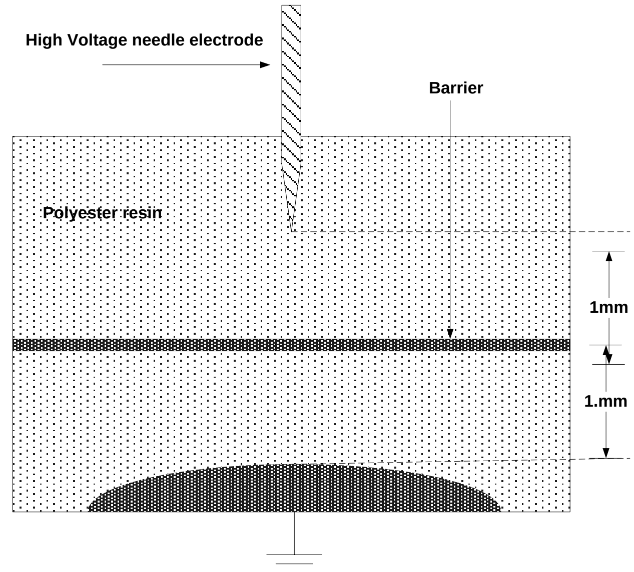

Fig. 4(a): Point plan Specimen containing barrier

4. Polariscope:

Growth of trees within the specimens was observed using a Polariscope. It is a device which reveals different strain pattern within the materials, such as polyester, that exhibits the photo electric effect. The use of Polariscope was of the crossed circular type.

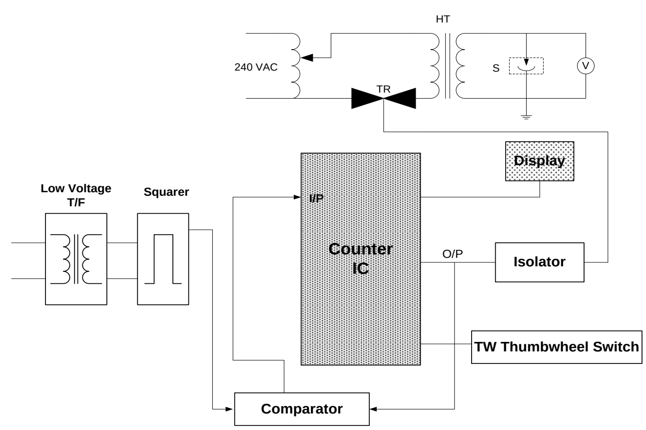

Fig. 4(b): Block diagram High voltage equipment

5. High Voltage Test equipment:

The high voltage test equipment used is illustrated in Figure 4(b) It consisted of a single phase step up transformer 240V/30kV, 1.5kVA, 50Hz supplied from a mains driven variable ratio transformer variac via a triac TR activated by a control unit. The auto transformer was used to control the magnitude of the voltage applied whilst the control unit regulated the number of cycles applied, in the range of 1 to 9999.The control unit, which was purpose built by the authors, is basically a counter. A block diagram showing the major components is shown in figure 4(b).

6. Experimental Procedure

A group of 20 identical specimens were tested for each type of barrier. Each specimen was clamped between brass electrodes in the test cell shown in Figure 5. The cell was then filled with pentane to suppress extraneous discharges.

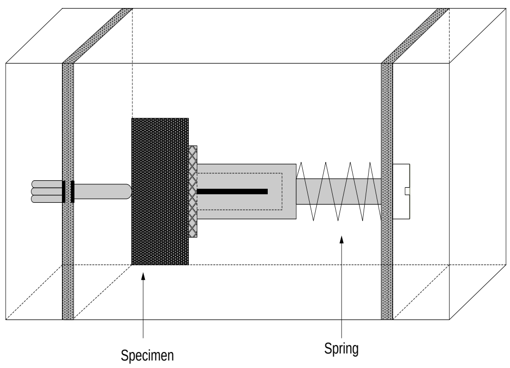

Fig. 5: Test Cell

28kV rms was selected to be the test voltage, because it produced intrinsic breakdown at the tip of the hypodermic needle leading to easily observed and repeatable tree growth in the dielectric. Voltage was applied in bursts, for a prescribed number of Cycles determined by the control unit until the specimen broke down. Following each application of voltage, the inter-electrode gap was inspected in the Polariscope for tree growth. Photographs were taken at various stages of growth using a camera mounted on the Polariscope eye piece.

7. Results and Discussion

The specimens, whatever the type and angle of barrier, were tested in batches of 20 to establish their life time. This was, as before, measured in terms of the number of cycle of the test voltage to cause breakdown by treeing. The test procedure was same as described above and test voltage 28kV applied in bursts using a triac controlled transformer. The specimens were inspected under a microscope, following each application of voltage, to observe there growth.

The first specimens tested were those containing no barrier. They had an average life time of 1400 cycle with a standard deviation of 560. The presence of polyester barrier increased the life time compared with no barrier. But angular position had no significant effect, as indicated by application of student's t test which showed that the difference in the mean values recorded for 0^0 and 45^0 was not significant. Similarly there was no significance to be assigned to the difference in the mean values recorded for the 90^0 and 45^0 cases. Observation of the three growth associated with each angle did indicate some difference of the tree form however. Thus, the channels produced in the 45^0 case were a little more profuse above the barrier than in the case of barriers disposed at 90^0 to the field. In the case of barriers aligned at 0^0 the growth was confined to the barriers region. Resin based specimens were tested to comparison purposes to other barrier. The observation of the tree growth in the presence of resin barriers are summarised in figure 6a for the horizontal barrier. This shows how the rate of tree growth changed as barrier approached. Referred to figure 6a treeing in the presence of the barrier is divided into three zone. Zone 1 where the treeing begin to grows toward the barrier. The tree is contained by the barrier in zone 2 and its growth toward electrode contained in zone 3 as shown in Figure 6b

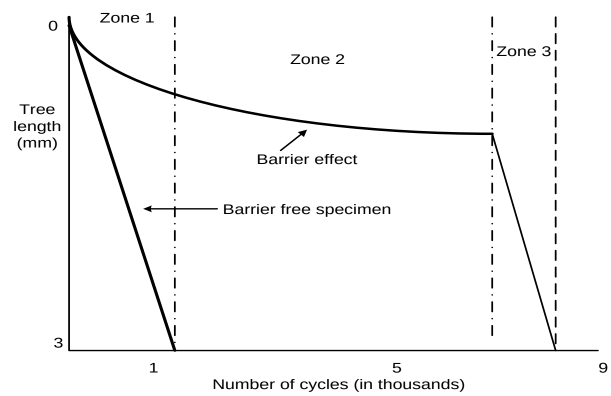

Fig. 6a: Treeing in resin base specimens

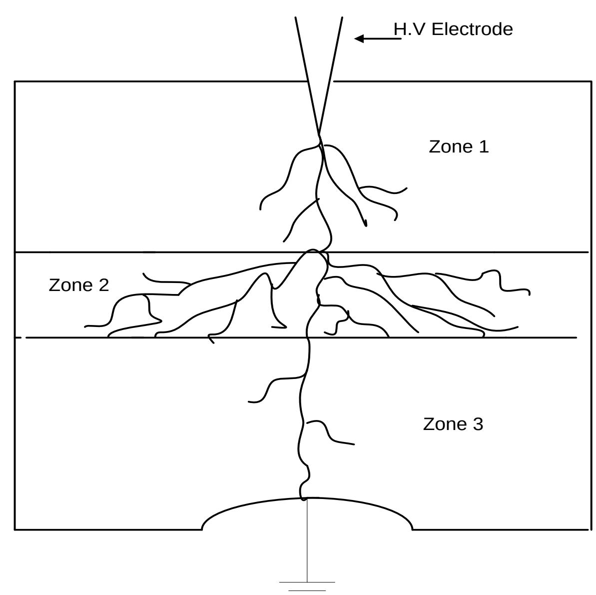

Fig. 6b: Tree pattern in resin base specimens

The second set of specimens tested were those containing glass barriers at zero degree. The results are summarized in table 2 Strain was induced by the glass barriers as is apparent from the background coloration in Figure 7. Figure 7 (a) shows the front view looking through the glass . It was impossible to obtain a clear image of the growth looking side ways along the interface layer of the resin. Sectioning of the specimens required to do so caused destruction of the glass resin interface.

Observations that could be made indicated the pattern of development as sketched in Figure 7(b). This shows that the glass has no direct contact with the tree growth, which splits into many branches indicating the presence of compressive strain around the strips of glass.

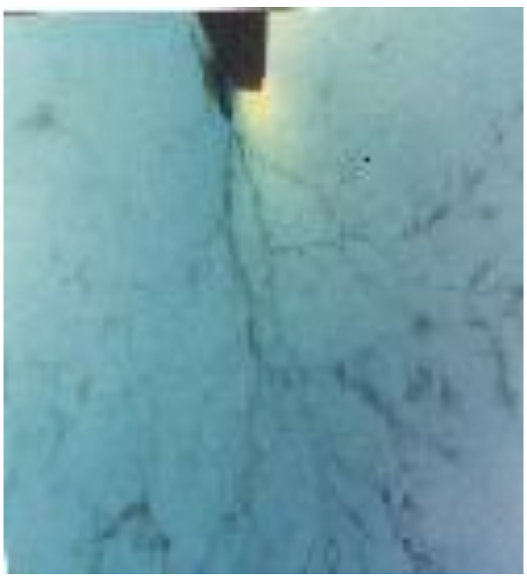

Fig. 7(a) :Front elevation

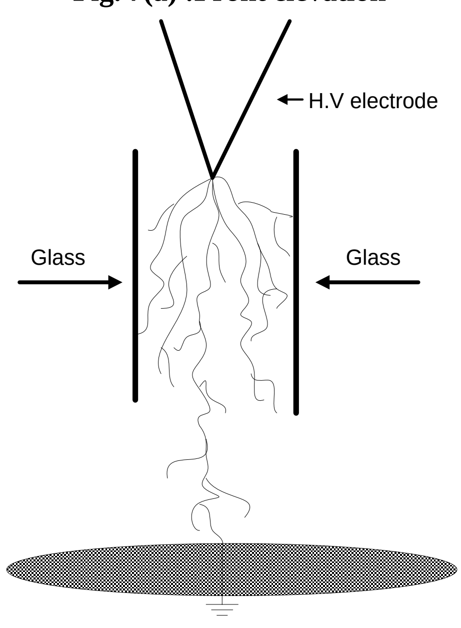

Fig. 7(b): side elevation

Figure 7 Tree growth in a specimen containing a glass barrier at $0^{0.}$

The mean life of the specimens containing glass aligned at 0^0 was increased by a factor of 6 compared with the resin barriers specimens aligned at 0^0 and 25 times greater than barrier free specimens.

The specimens with the glass inclined at 45^0 to the axis of the field offered much more resistance than those at 0^0 as is clear from Table.1. Tree initiation time and the degree of strain induced was the same as for the glass barrier set at 0^0 but growth was much slower tree preferred to grow sideways with many branches containing numerous tiny channels. Tree pattern shown in Figure 8 when barrier disposed at 45^0

Fig. 8: Tree growth in a specimen containing a glass barrier at 45^0

Tree growth was along the resin-barrier interface but no touching the barriers itself .In none of the 20 specimens tested did trees penetrate the glass barriers.

Table 2: Summary of test results

Barrier type	Angle with field	Average Cycle to Bd	S.D
Resin	0^0	5657	3160
Resin	45^0	7109	3170
Resin	90^0	8850	5981
Glass	0^0	36065	22261
Glass	45^0	93150	21280
Glass	90^0	12400	3555
Melinex	0^0	5160	3288
Melinex	45^0	46596	32462
Melinex	90^0	82692	21233
PTFE	0^0	1370	602
PTFE	45^0	12250	5374
PTFE	90^0	17760	66248

The specimens containing glass barrier at 90^0 to the axis of the point-plan field had shorter life time than 0^o and 45^o counterparts. Strain retarded and diffused the growth as barrier was approached, subsequent fracture of the glass providing an easy path for growth through to the lower side of the glass. The pattern of tree growth is shown in Figure 9.

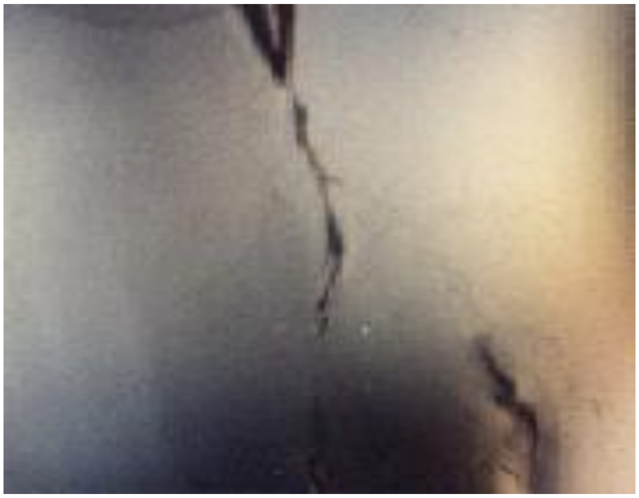

Fig. 9: Tree growth in a specimen containing glass barrier at 90^0

In the case of of Melinex and PTFE,, the life time of the specimen film aligned to the 0^0 with respect to the field was less than the resin and glass at 00. It is much less when compared with the latter, the reason being that there is less compression in the specimens containing Melinex and PTFE compared with glass.

The reduced compression in these specimens follows from poor work of adhesion with the surrounding resin being lowest in the case of PTFE. Poor work of adhesion also lead easy debonding between the barrier and resin. The tree channels were forced to concentrate along the weak interface probably due to lack of compression and it is this tendency which led to premature failure of the PTFE specimens.

Specimens with Melinex barriers inclined at 45^0 to the field had life times approximately one half of their glass counterparts whilst the life of the PTFE barrier inclined at 45^0 was approximately one tenth that of the glass equivalent. Debonding occurred when the tree reached the film barrier in both Melinex and PTFE cases. Considering first the Melinex, debonding let to the spreading of tree growth across the Melinex-polyester interface. Eventually the Melinex specimens broke down through the barrier at point close to the earth electrode. The spreading effect accompanying the debonding served to retard progress to this point.

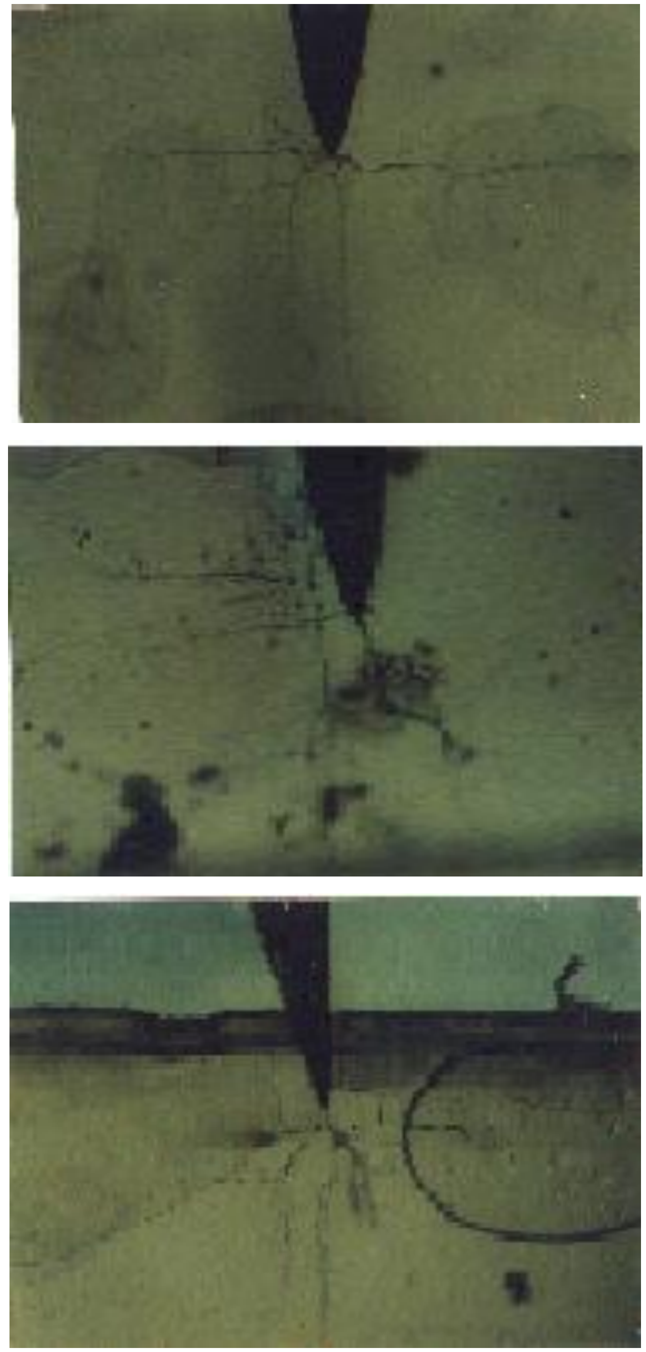

Fig.10 Pattern of Tree growth in a specimen containing melinex barrier at 45^0

Specimens containing Melinex arranged at 90^o to the axis of the field exhibited life time similar to that of glass, tree growth being retorted by delaminating and the creation of new trees at the resin interface as explained and shown previously. In the caser of PTFE films the life of the specimens at 90^o was greater than for glass at 90^o. This was because the initial channels debonded the P.T.F.E and did not penetrate presumably because of its high melting point.

Development was confined to broadening of signal channels leading in most cases to puncturing of the barriers. In some instances broadening of the incident channels was also accompanied by surface tracking to the failure to the specimens over the edge of the film.

8. Conclusion:

The work described demonstrate that growth of tree and pattern depend upon the orientation of the barrier and work of adhesion of barrier with matrix. Barrier offer high resistance to tree growth when disposed at 45^0 provided barrier material has high work of adhesion.

9. References:

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