

Effects of Zinc Oxide Barriers on Electrical Tree Growth in Solid Insulation

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Abstract: The effect of zinc oxide (ZnO) on tree growth has been extensively investigated in this paper. The fillers are widely added in the insulation partly for reinforcement and also for suppression of tree initiation and their growth. The addition of zinc oxide (ZnO) as a filler into polymer insulation material also shows a non linear effect in dc conductivity when volume fraction of filler is above a certain level. In this work, zinc oxide (ZnO) employed in clear polyester resin as a barrier. High voltage 28kV rms is applied in the form of burst. The growth and nature of tree monitor on polariscope on regular interval. The life time of the specimen was filled with ZnO and ZnO as a barrier, is increased many fold. The results zinc oxide (ZnO) specimens are compared with Aluminium Oxide (Al_2O_3) barrier. In the case of Aluminium oxide (Al_2O_3) when tree was blocked by the barrier, the branches of the tree become wider because of discharge activity and no such activity was found in the case of zinc oxide (ZnO). Ten specimens of zinc oxide (ZnO) barrier were tested and none of them breakdown.

Key words: Zinc oxide % Insulation % Ceramic % Barrier % Electrical tree

INTRODUCTION

Zinc oxide (ZnO) is used in varistors in power systems where its conductivity is enhanced by the introduction of Bi_2O_3 , CoO, MnO, Cr_2O_3 and Sb_2O_3 . The non-linear conductivity of zinc oxide (ZnO) ceramics has been the basis of their development as varistor products for surge arresting and over voltage application in power system. In recent years, research has been undertaken into properties of polymeric insulation materials containing volume fractions zinc oxide. It was shown by Donnelly and Varlow that inclusion of zinc oxide (ZnO) in epoxy resin is capable of producing non-linear conductivity when the filler volume fraction exceeds the percolation threshold. Due to non-linear conductivity the resistance to electrical growth is increased and also size of the particles further enhances the life of the insulation. It was shown by Auckland, Rashid and Varlow that the growth of trees was greatly influenced by the particles of Aluminium oxide (Al_2O_3). We are more concerned with the zinc oxide (ZnO) in its more natural state and the present work is not concerned with these materials (Bi_2O_3 , CoO, MnO, Cr_2O_3 and Sb_2O_3). Although this show non-linear conductivity with voltage it is not as marked as in

varistor material but nevertheless good enough to check the proposal that non-linear conductivity improves insulation life. Zinc oxide (ZnO) has a high melting point, high work of adhesion with polyester resin and high fracture toughness making it comparable to Aluminium oxide (Al_2O_3) as far as its mechanical characteristics and consequently mechanical resistance to tree growth is concerned. Thus it was a natural choice as filler in test designed to investigate the value of non-linear conductivity as a tree suppressor, the Aluminium oxide (Al_2O_3) providing a reference for comparison. The development of the tree in the presence of zinc oxide (ZnO) barriers and within polyester resin completely filled with zinc oxide (ZnO) power was tested and the results were compared with those from identical specimen using Aluminium oxide (Al_2O_3) as filler to reveal the effect of non-linearity.

MATERIALS AND METHODS

Polyester Resin: The materials used in this investigation were thermosetting polyester resin as matrix, aluminum oxide and zinc oxide as filler. The resin was supplied M/S Scott B ader and known as resin C. Because of its easy

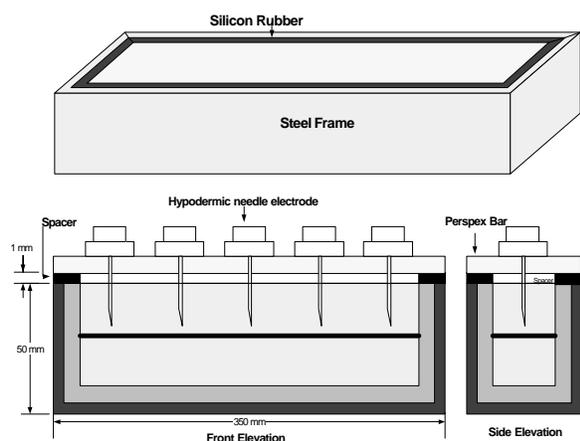


Fig. 1: Specimen manufacture method

handling, rapid curing, good physical and electrical properties, dimensional stability and optical quality polyester resin was used.

Zinc Oxide: Zinc oxide used was of general chemical grade manufactured by M/S BDH. It was 99% pure and had an average granule size of 6 μ m comparable with the Aluminium oxide particles of size 4.5 μ m. The specimens contained point-plane electrodes of separation 3mm. and barriers were cast between point and plane electrode.

Aluminium Oxide: Aluminium oxide was employed as filler because of its physical prosperities. Since it has high surface energy so it adheres well to the surrounding polyester and it has work of adhesion and fraction toughness.

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 1. 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.

The specimens were made in two stages. First, a layer of resin approximately 4mm deep was poured into the bottom of the mould and allowed to set. A second layer of resin mixed with particles of the required size was poured on top of the hardened surface. Hypodermic needles were used as point electrode because they are sharp enough to

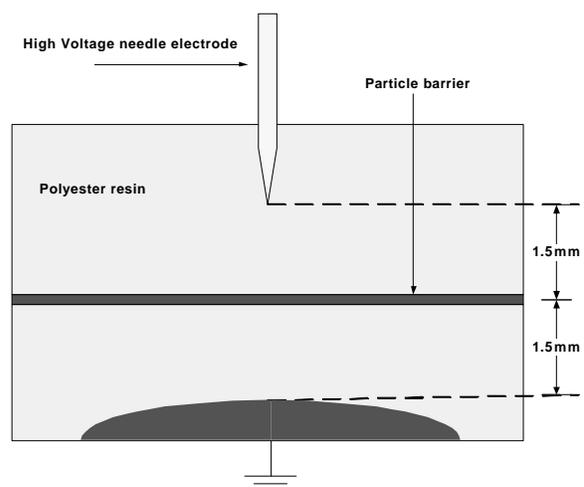


Fig. 2(a): Point plan Specimen containing barrier

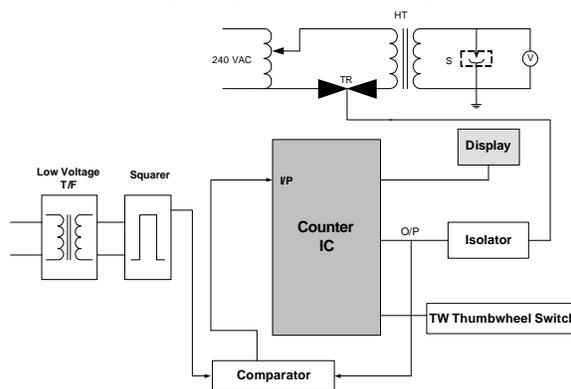


Fig. 2(b): Block diagram High voltage equipment

support tree growth, cheap reproducible and readily available. High voltage 28kV A.C, 50Hz was applied in the form of burst through counter which count number of cycles applied to the specimen.

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.

High Voltage Test Equipment: The high voltage test equipment used is illustrated in Figure 2(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.

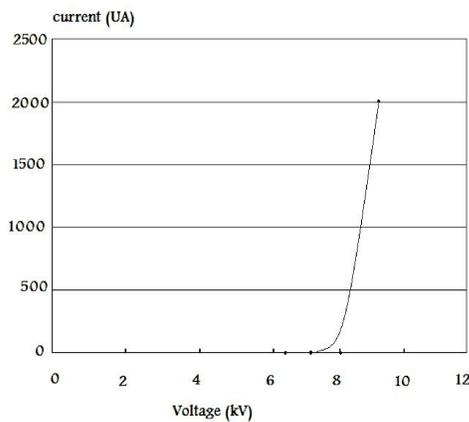
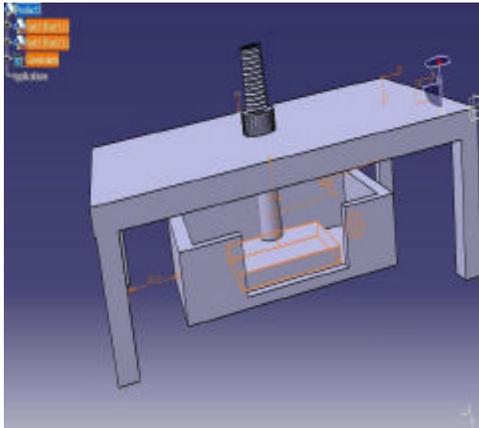


Fig. 4: Specimen manufacture for V-I measurement

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 2(b).

V-i Characteristics Measurements: The voltage versus current characteristics of zinc oxide and aluminum oxide layers were measured. The layers were cast between rectangular bronze electrode, of length 36*25mm and thickness of 7mm. The lower plane electrode rested on the bottom of a silicon mould.

The second electrode was attached to a threaded rod which screwed into a tapped hole in a beam resting on a frame over the top of mold. The required electrode gap was obtained by screwing the upper electrode down until it just touched the lower electrode. The threaded rod was then turned in the opposite direction until the required gap, which was 1mm in each case, was achieved. The mould was then filled with particle filled resin. The resin was allowed to set after which it was cured at 80°C for three hours and allowed to cool naturally to room temperature.

The V-I characteristics of zinc oxide and Aluminium oxide were obtained using a d.c voltage source of 15kV, 2mA. A current limiting resistor was connected in series with voltage source. A digital ammeter was connected in the circuit and the voltage rose until the meter showed a steady reading. The voltage was raised further in steps and corresponding current readings noted at each step until the limit of the voltage source was reached. The V-I characteristics of zinc oxide is shown in Figure 4. The same procedure was adopted for measuring V-I characteristics of Aluminium oxide.

Experimental Procedure: A group of 20 identical specimens were tested for each type of particles. 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 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.

RESULTS AND DISCUSSION

Zinc oxide (ZnO), Aluminium oxide (Al₂O₃) barrier specimens and filled specimens were tested. The results are summarized in Table 1 below.

First, considering the zinc oxide (ZnO) barrier specimens. From the table 1, it is clear that the life of the zinc oxide (ZnO) barrier specimens is very high. Direct comparison is not possible because at no time did a tree penetrate the zinc oxide (ZnO) barrier. When the tree hit the barrier it diffused with no forward movement after that.

Table 1

Specimens Type	No of specimen tested	Mean cycles to Breakdown	Standard deviation
ZnO Barrier	10	*	*
ZnO filled	20	86729	29635
Al2O3 Barrier	20	17600	4516
Al2O3 filled	20	17200	4202

*None of specimens broke down even after more than 300,000 cycles

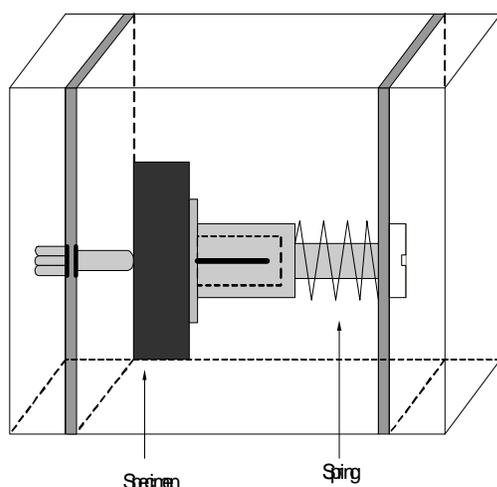


Fig. 5: Test Cell

In the case of the Aluminium oxide (ZnO) when a tree was blocked by the barrier, the branches of the tree became wider because of discharge activity. No such activity was found in the cases of zinc oxide (ZnO). Tree initiation time and growth towards the barrier in both cases was approximately same but growth inside the barrier was quite different. Tree growth in the presence of both types of barriers is shown in Fig.6.

In the filled resin no activity could be observed within the material. The only indication of treeing was obtained when the tree penetrated the filled resin emerging into the clear resin near the plane electrode. The life of the zinc oxide (ZnO) filled resin is very high compared with Aluminium oxide (Al_2O_3) being about five times greater than the latter. The cycles to breakdown after the penetration were same in both cases.

In the case of the barrier, when a tree hit the zinc oxide (ZnO) its advancement virtually stopped. It was observed in the case of aluminum oxide barriers and other that when tree growth stopped, the tree channels became wider due to discharges. It was also observed in other materials that when tree growth in the direction of barrier is restarted, it restarts spreading along the barrier resin interface as in the case of Aluminium oxide (Al_2O_3) loaded fabric. No such behavior was noted in the presence of zinc oxide (ZnO) barriers. No growth along the barrier was observed neither there was any widening of the channel. This behavior possibly may be explained by assuming that the zinc oxide (ZnO) barrier dissipates charges, thus as a tree channels hits the barrier, the zinc oxide (ZnO) granules in the vicinity start conducting in accordance with the V-I characteristics shown in Fig 4. The result is reduction of the concentration of field at the tip and hence stopping further development.



Fig. 6 Growth of trees in

Fig. 6(a) ZNO Barrier

Fig. 6(b) Aluminum oxide barrier

The filled zinc oxide (ZnO) specimen gives a higher life compared with their Aluminium oxide (Al_2O_3) counterparts, but ultimately broke down. In the barrier case, zinc oxide (ZnO) had no direct contact with the high voltage electrode. The only contact was through the tree channels. But in the filled specimens, the high voltage electrode was embedded in zinc oxide (ZnO). The fact that these specimens brake down might be due to increases in local temperature and thermal degradation around the pin tip.

V-I characteristics of zinc oxide (ZnO) is shown in Fig.4. Up to 6 kV no reasonable current flowed, after which a few micro amperes were detected. As the voltage was raised to 7 kV the current increased rapidly to be the order of milliamps. In the case of Aluminium oxide (Al_2O_3) specimen, no reasonable current flowed up to 5kV after which irreversible breakdown of the specimen occurred.

Many theories have been proposed to explain conduction in zinc oxide (ZnO) particularly for the material used in Varistors, which contains about 96% ZnO and 4% other oxides such as Bi_2O_3 , MnO , CaO , Sb_2O_3 and Cr_2O_3 . However the conduction mechanism of Zinc oxide (ZnO) in general still remains a problem to be solved.

The theories given for Zinc oxide (ZnO) Varistor conduction are

- C Avalanche breakdown
- C Space- charge – limited current
- C Thermal activation over double Schottky barrier
- C Simple tunneling.

Breakdown processes in semiconductor junction often proceed via avalanche multiplication. The current-voltage characteristics associated with the process are extremely sharp and correspond in many in many cases to the alpha carrier multiplication factor of 1000. Avalanche breakdown is, however, characterized by positive temperature coefficient of breakdown voltage. Zinc oxide (ZnO) Varistors exhibit a negative temperature coefficient.

The-space-charge limited process describes condition within an insulator provided with ohmic contacts. This theory is applicable for explaining the effect of additives on the non-ohmic properties. Presently, it has been reported that the highly non-ohmic property of the kind observed in the voltage region above the threshold between non-linear and the linear parts of the V-I characteristics is consistence with the Fowler-Nordheim tunneling process, whilst the conduction mechanism in the voltage region between the threshold voltage follows the thermally activated Frenkel-Poole law of the Schottky barrier.

These theories explain the form the voltage current characteristics and their temperature dependence. However they do not provide explanations of curtain experimental results, such as the effect of additives and the asymmetrical degradation of voltage-current characteristics.

In our case we use 99% pure zinc oxide (ZnO) with 1% impurity of unknown composition, mixed with polyester resin. It is therefore assumed that the semiconductor-insulator –semiconductor structure be composed on an inter granular layer sandwiched between the Schottky barrier formed at the surface of n-type semiconductor zinc oxide (ZnO) grains. Initial increases in voltage produces no reasonable current flows in the circuit and the material behaves as an insulator.

The energy supplied by the source is not enough for electrons to cross the insulation barrier of the polyester resin. As the voltage is further increased, conduction electrodes in ZNO gain sufficient energy to cross the insulation zone. After that the current increases and jump from micro ampere level to mille ampere level. When compared with zinc oxide (ZnO), Aluminium oxide (Al₂O₃) has characteristics of typical solid breakdown.

Initially, no current flows but further increases in voltage results in complete breakdown of the specimens.

CONCLUSIONS

The present work is mainly concentrated to investigate effect of zinc oxide (ZnO) on electrical treeing. Zinc oxide (ZnO) employed in point plan electrode as a barrier and also as filler. The following exciting results have been achieved.

- C In the filled resin no activity could be observed within the material. The only indication of treeing was obtained when the tree penetrated the filled resin emerging into the clear resin near the plane electrode. The life of the zinc oxide filled resin is very high compared with Aluminium oxide being about five times greater than the latter. The cycles to breakdown after the penetration were same in both cases.
- C In the case of ZnO barrier specimens, when tree hit the barrier its growth virtually stopped presumably, due to conduction of zinc oxide granules in the vicinity in accordance with the V-I characteristics. Reducing the concentration of field at the tip and hence stopping further development.
- C ZnO found very effective for stopping the growth of electrical trees. It is presumably non linear characteristics of the insulator due to addition of ZnO. However other factors like mechanical strength of the insulator, environmental degradation etc, need further studies.

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