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ELECTRICAL TREEING IN CERAMIC-BASED INSULATING MATERIALS ($BaTiO_3$ - SiO_2)

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ABSTRACT

The process leading to the development of electrical trees in ceramic-based materials ($BaTiO_3$- SiO_2 system) under the influence of relatively low a.c. signals and induced vibration frequencies was studied. The breakdown strengths of the chosen material (Ba TiO_3 system) was conducted under oil whereas the dielectric properties were determined by impendence method. It was observed that the tree-like structures were of two types and that the initiation could have been due to partial discharges that arose from microcracks, pores and other similar defects. This equally shows that the mechanism of the initiation of an a.c. tree and that of a d.c. trees are similar. Thus, if a.c. voltage is considered as a repetition of charging and discharging processes, then one can understand that some likeness could exist between the phenomena.

Keywords: Electrical treeing, ceramics, insulators, breakdown, micro cracks.

INTRODUCTION

The discovery of electrical discharges, which are responsible for the destruction of the dielectric characteristics in solid materials, is not very recent. It dates as far back as 1912 when Rayner reported the process of electrical discharges in polyethylene system. Recently research works and development have proved that electrical discharges are increasingly presenting serious problems for most dielectric insulators (Eichhorn, 1996) The problem include voltage surges and damage to electrical and electronic systems. This led to attempts in solving the problems, which eventually resulted to the discovery of the phenomena known as electrical treeing in dielectrics (Kitchin and Preot, 1956). Between 1920 and 1936, work on the concept of treeing or internal tracking as it was then called has been on and its results were reported by Robinson in 1936. The report stated that it was electrical treeing that caused cracks and voids within the system. Thus the initial failure of a paper-oil interface that was usually applied during cable construction process was credited to treeing effect arising from microcracks, voids and structural defects.

The above report generated an increasing interest in dielectric pre-breakdown phenomena, which yielded results that appear to confirm the fact that electrical treeing was a pre-breakdown process. It was equally deduced that treeing occurs in dielectric insulating materials that has alternating signal with divergent electrical stresses (Eichhorn, 1996). Saito, et al, (1977) observed that treeing sources originated from sites where impregnated moisture, impurities, gas-field pores, microcracks or microstructural defects were found. This analysis contradicted that of Robinson (1936). Most recently, other workers (Arab and Auckland, 1999) stated that organic polymeric insulation suffered from long-term degradation at low alternating voltage stresses due to increasingly vibration period. This condition, which seems to agree with the work of Eichhorn, (1996) who said that vibrations in part was responsible for the tree-like structures of the observed discharge-channels that emanated from protrusions and inhomogeneities.

Previously, it has been observed that under normal operating environment, electrical treeing involves a long-term but gradual erosion process, which initiates the development of tree-like structures of fine finger-like or deltaic conducting channels. These channels sometimes emanate from localised regions of concentrated stress. Some cases have been noted at regions associated with voids, pores (filled with moisture or gases) and other higher conducting inhomogeneities within the dielectrics (Auckland, 1986)

It was explained (Auckland, 1986) that the nature of damage caused by electrical treeing comprised fibrillar discontinuities and clusters of micro-voids that were commensurate with brittle fracture. Equally important was the fact that brittle fracture was accelerated by increasing frequency of low voltage stresses. This implies that as the frequency of low electrical stress increases, the treeing process is accelerated.

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Table 1: Characteristics of Microwave fired BaTi O3-Si2System

Sample	Compositio (wt% nominal purity)	Dielectric constants			Density (g/cm³)	Water absorption (%)	Dissipation factor at 35°C	Bulk Resistivity (Ohms-cm)
		35°C	270°C	413°C				
A	96.80	9.06	9.54	9.92	2.68	0.00003	0.00029	3.68
B	97.05	9.27	9.68	10.12	2.85	0.00008	0.00064	3.75
C	99.62	9.48	9.95	10.18	3.28	-	0.00018	4.09
D	99.87	9.68	9.97	10.34	3.56	-	0.00009	4.56

Table 2 Frequency induced breakdown values and Teeing effect.

	Breakdown Frequency (kV/mm) at induced frequency				Presence of Tree at induced frequency				
Samples	50 Hz	10 kHz	100 kHz	10MHz	Sintering (°C)	50 Hz channels	kHz	100kHz	10MHz
A	23.04	11.20	8.20	5.41	1600	√	√	-	-
B	24.10	19.01	10.04	3.41	1650	√	√	-	-
C	27.12	21.38	12.18	2.18	—	-	-	-	-
D	30.45	20.24	7.24	2.54	1750	-	-	-	-

The quest for the development of new improved construction materials for electrical insulating systems such as high voltage insulated power cables, and transformer insulators has increased the depth and volume of research in electrical treeing. Thus recent research on formulating of additives for the composition of new products that could assist in voltage stabilization have over the last decade produced high insulating resistance materials (Nawata, 1994).

In 1974 and 1976 Budenstein and Eichhorn respectively established the mechanism of treeing as a pre-breakdown process in solid dielectrics. Thereafter, a model for the complete process of electrical breakdown in organic solid materials was proposed. Byoung-Chal Shin and Ho-Gi Kim (1988) attempted to apply the model on fast fired Ba Ti O_3 ceramics but discovered to their dismay that the break-down was initiated by partial discharge inception field at 250 V/mm. In addition it was found that whenever local field enhancement within pores was absent the treeing process was equally absent.

The present work attempts to explain the observed treeing in ceramics based systems. This could be achieved in terms of established theories and the measured data obtained from breakdown processes under applied vibration frequencies. Other electrical properties will of necessity be investigated and related to the treeing process. Attempts will be made in explaining the mechanism of treeing in ceramics with regard to the data.

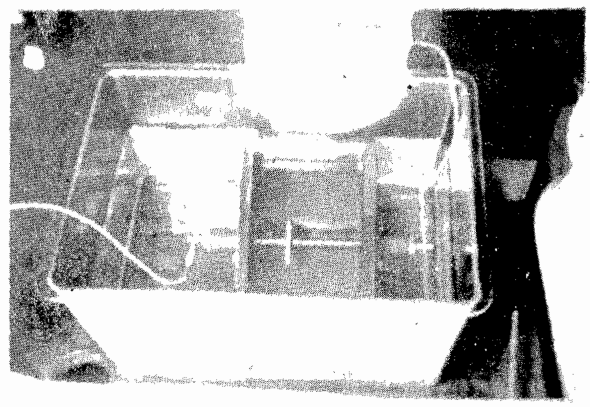

Fig. 1 Sample in an oil bath

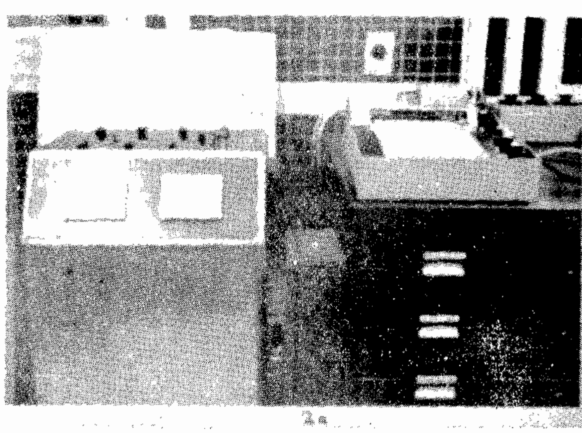

Fig. 2a Electrical breakdown control console

EXPERIMENTAL METHODS

The Samples obtained from WADES

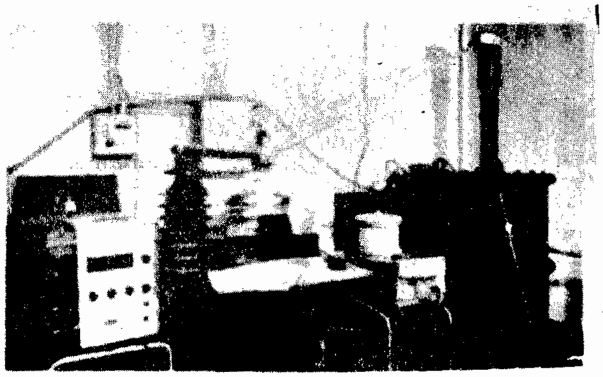

Fig. 2b Control console with a chart and circuit breaker

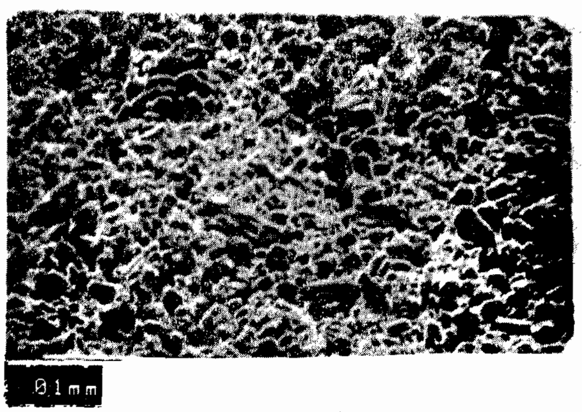

Fig. 3 Microstructure of sample A sintered at 1600°C

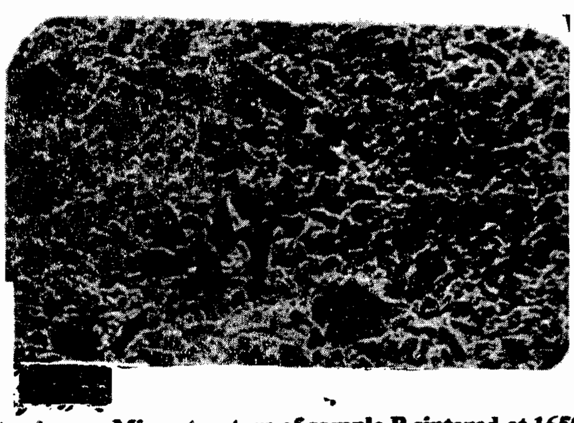

Fig. 4 Microstructure of sample B sintered at 1650°C

CERAMICS LTD were physically examined before the characteristic-properties were determined. The specimens were microwave sintered at four different temperatures. Properties such as density and percentage of water absorption were determined by simple Archimedes's technique and weight increase through prolonged soaking in distilled water respectively. The electrical breakdown tests of the disc specimens were performed in the manner described elsewhere by Owate, and Freer (1991). The specimens were initially polished, cleaned and gold coated. Each sample was then placed between the electrodes system placed in an oil bath as shown in Figure 1. In addition, the tests Console with circuit breakers are shown in Figures 2a and 2b.

The circuit breaker is an important component in this work since it was necessary to distinguish flashover and corona discharges from the actual initiation of breakdown (where treeing is expected). The electrode system used for the present study was similar to that used for other studies (Owate, 1989). Standard a.c. breakdown tests were conducted at a temperature of 18°C and induced vibration frequencies as shown in Table 2. The craters and conduction channels (formed during the breakdown process) were later examined with scanning Electron microscope (Philips 525 Model). The chemical analyses of the samples were performed by an energy dispersive system (EDS) facility of the Philip Scanning Electron Microscope. The dielectric constant, dissipation factor and bulk resistivety were later measured using a frequency sweep impedance meter (Solariton, 1176 Model). Details of the methods have been explained by others (Owate and Chukwuocha, 2002).

RESULTS AND DISCUSSION

The micrographs of samples A, B, C, and D received from WADES CERAMICS LTD, England are presented in Figures 3, 4, 5, and 6. The indicated history of the samples showed that they were microwave sintered at 1600,1650, 1700 and 1750°C respectively after pre-firing at 700°C for ten minutes. This was reflected in the graded microstructures and measured electrical properties (Tables 1 and 2). It could be observed that samples sintered at 1700 and 1750°C (Figs 5 and 6) had massive grain growth. This suggests that increasing microcracks, pores and other defects due to thermal stress have been introduced. They might have been the cause of the graded grain sizes and varieties of shapes. Since such defects are usually the consequence of grain grow that might have caused the effect. It had relatively smaller but compact grains with well-banded structures. In Table 1 and 2 are the empirically determined characteristics behaviour and the nominal compositions (wt %) of the samples.

Table 1 shows that resistivities increases with increasing sintering and measurement temperatures; (Owate and Freer, 1991) whereas dissipation factors decreased with increasing sintering temperatures. Also only samples A and B absorbed very low percentage of water while samples C and D did not. Even though samples C and D had higher densities than A and B, it was obvious from the micrographs (Fig 5 and 6) that excessive grain growth occurred. This in part introduced several defects such as microcracks, porosities and other impurities. This implies that samples C and D were relatively of poor electrical quality.

Table 2 shows that electrical breakdown increases with sintering temperatures and decreases with induced vibration frequencies. Consequently, samples A and B broke down electrically through the initiation of Treeing process (Figure 7, 8, 9, 10 and 11) at specific induced frequencies of 50 Hz and 10kHz. No Treeing structures were observed for samples C and D at all induced frequencies. Also for samples A and B. no tree-structure was noticed at frequencies higher than 10 kHz. This could be due to the poor quality of samples C and D and very high-induced frequencies at 100 kHz and 10 MHz. This observation is very significant because it is an indication that electrical treeing in ceramics depends upon the induced vibration frequencies and the nature of the microstructure of the system. This could be the reason for the different type of Treeing structures at 50 Hz for samples A and B. The structures were of multiple branches of bush-like models that appear to have arisen from thermal destruction stress. Such structure could have been formed by partial discharge inception field (usually low a. c. induced field frequency) (Byoung-chul and Kim, 1988). It has been well known that, with comparatively low a.c. voltages a.c. Treeing process initiates branch-like structures with increasing voltage and frequency. This could develop into a typical root-like tree with a major crack on the condition channel (Suit et al 1977). In addition, figures 9, 10, and 11 indicated similar structures at 10 kHz and equally at breakdown strength's of 19.01, 19.20 and 20.46 kV/mm respectively. These results indicate that the tree-initiation voltages achieved by using induced vibration frequencies are much lower than the breakdown voltages. This might have been caused by the initial introduction of microcracks and pores arising from the induced vibration frequency. Arbab (1999) has in his work on Polythene said that trees developed initially along the interface between electrode and the polymer, and then transferred outwards into the bulk of the polymer thereby creating a belt of damage, which emanated from the metal-solid interface and grow wider as time goes by. This could be why one

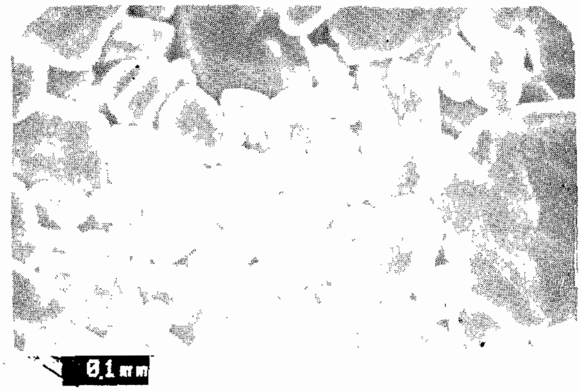

Fig. 5 Microstructure of sample C sintered at 1700^{0}C

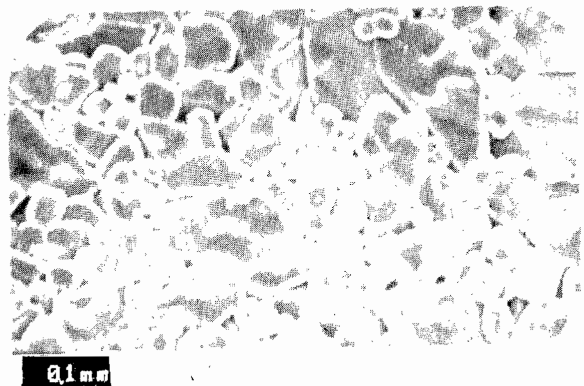

Fig. 6 Microstructure of sample D sintered at 1750^{0}C

Fig. 7 Treeing in sample A at 50Hz

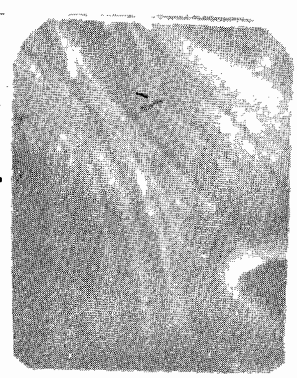

Fig. 8 Treeing in sample A at 10kHz

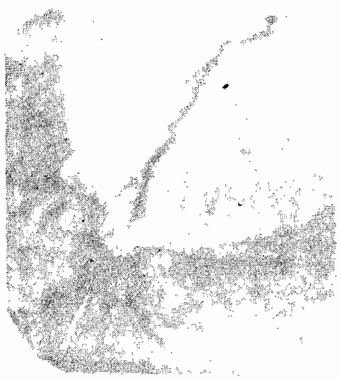

Fig. 9 Treeing in sample B at 50Hz

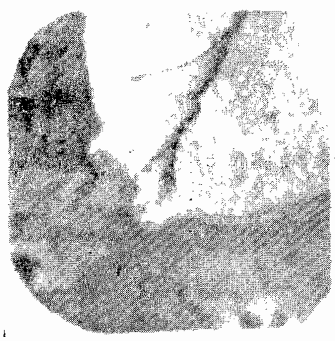

Fig. 10 Treeing in sample B at 10kHz

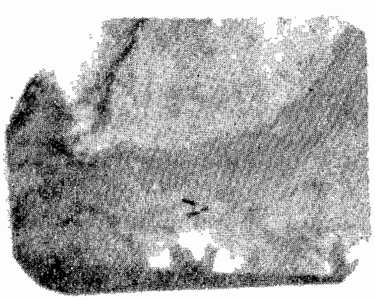

Fig. 11 Breakdown creater for sample C at 50Hz

thinks that electrical stress on brittle material such as Ba TiO_3 system might have introduced microcracks at the inception of induced vibration frequencies. This means that treeing in ceramics followed the formation of microcracks emanating from interface between the hemispherical electrode system and the ceramics material. These cracks, once developed, provide a source of partial discharge process that is necessary to induce tree-growth. Consequently, microcracks resulting from brittle fracture was caused by the cyclical electrostatic forces (a.c. voltages). This support the fact that trees originate from pores and other similar defects. It is well known that impurities create centers of electrostatic stress concentration thereby leading to the evolution of microcracks and subsequent tree-growth that have been observed in the present materials after breakdown. It becomes imperative to suggest that the observed treeing structures for $BaTiO_3$ ceramics was caused by the variation of breakdown strength with frequencies, sintering temperature and subsequent quantity of samples.

CONCLUSION

A tree-initiation process and its structures have been noticed in ceramic-based materials by using a.c. voltages and induced vibration frequencies. It was observed that the tree-like structures were of two types and that the initiation could have been due to partial discharges that arose from microcracks, pores and other similar defects. This then shows that the mechanism of the initiation of an a.c. tree and that of a d.c tree are similar. Thus, if a.c. voltage is considered as a repetition of charging and discharging process, then one can understand that the expected likeness between both phenomena.

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