# Comparative Analysis of Dielectric Properties of Enamel Filled with Various Nanofillers such as $ZrO_2$, $Al_2O_3$, CNT and ZnO

D. Edison Selvaraj
Department of Electrical and Electronics Engineering,
Mepco Schlenk Engineering College,
Sivakasi, India

S. Usa
Division of High Voltage Engineering,
College of Engineering, Guindy,
Anna University, Chennai,
India

C. Pugazhendhi Sugumaran
Division of High Voltage Engineering,
College of Engineering, Guindy,
Anna University, Chennai,
India

**Abstract:** The last decade has witnessed enormous improvement in the area of nanofillers on electrical, thermal and mechanical properties of polymeric materials. The dielectric and thermal properties of standard enamel and various nanofiller mixed enamel were detailed and analyzed. Nanopowders of $ZrO_2$, $Al_2O_3$, CNT and ZnO were used as filler. Ball mill method was used to synthesize various nanofillers such as $ZrO_2$, $Al_2O_3$ and ZnO. CNT were synthesized by the process called chemical vapour deposition (CVD). The basic dielectric properties such as dielectric strength and partial discharge characteristics of the enamel filled with various nanofillers such as $ZrO_2$, $Al_2O_3$, CNT and ZnO at various proportions (1%, 3% and 5%) were analyzed and compared with the properties of the standard enamel. The experimental results show that enamel mixed with nanofillers has higher dielectric properties when compared to that of standard enamel.

**Keywords**: **CNT, $ZrO_2$, $Al_2O_3$, ZnO, CVD, Ball mill, dielectric strength and partial discharge inception and extinction voltage.**

## 1. INTRODUCTION

In the last few years, it has been observed that the use of nanoparticles in the matrix of polymeric materials can greatly improve the thermal, mechanical and electrical properties of polymeric nanocomposites [8]. The basic understanding of electrical breakdown of materials and electrical surface flashover phenomena of such advanced materials must be investigated before they can be commercially available [11]. The findings of such studies were essential for the development of nano-electric and other advanced materials and the techniques to predict the reliability of the advanced electrical systems which utilize these materials. The nanostructured polymeric materials were object of great interest by the researchers. The reasons of this interest were well-known: several mechanical, thermal and electrical properties can be improved by adding few percent of inorganic nanofiller [3]. The concentration of nanofiller was determined by Lichtenecker - Rother Equation. This paper was focused on the characterization of dielectric properties of standard enamel and various nanofillers mixed enamel.

## 2. EXPERIMENTAL

### 2.1 Sample Preparation

The nanocomposites were prepared by radical initiator curing method. Diamino Diphenyl Methane (DDM) was used as curing agent. The DDM was melted at 60° - 80°C for 10 minutes. The enamel, resin and melted DDM were mixed in a beaker. The mixture was poured into the die coated by a Teflon sheet. The die was heated at 120° C for 3 hours. Then, the die was taken away from the oven and it was cooled for 1 hour. Thirteen different samples were produced [8]. The process involved for preparation of nanocomposites was shown in Figure 1.

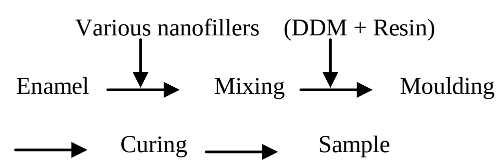


Figure 1. Sample Preparation

### 2.2 Synthesis of carbon nanotubes

The synthesis of CNT consists of three stages: Preparation of Catalysts for CNT, CVD process shown in figure 2 and Purification of Carbon Nanotubes. The micropowders of $ZrO_2$, $Al_2O_3$ and ZnO were converted into nanopowders by using Ball mill method.

Figure 2. Experimental setup of CVD system

The particle size of the powder was analyzed by using the SEM characterization techniques. From the results, the particle size was found to be tens of nanometer.

## 2.3 Partial Discharge Measurements

The partial discharge experiment was carried out inside the shielded room to avoid the external noises. Figure 3 shows the circuit arrangement for the partial discharge measurement. The initial discharges occurring in the samples were captured by a high quality oscilloscope. The inception and extinction voltages were noted.

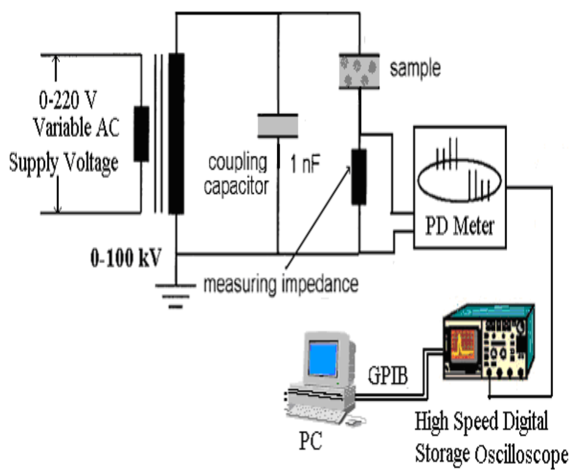


Figure 3. Circuit diagram for Measurement of Partial Discharge

A standardized electrode setup for the determination of the breakdown voltage and partial discharge inception and extinction voltage of solid samples as per IEC 243 was shown in figure 4.

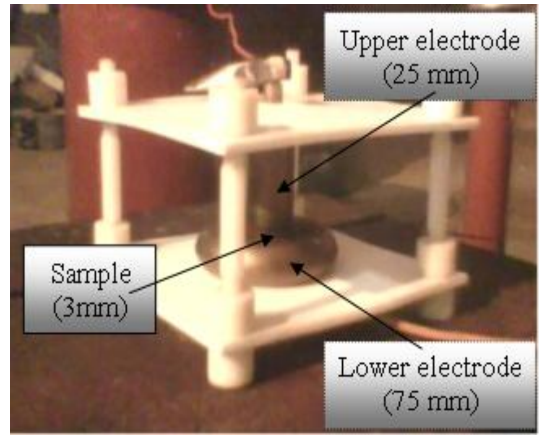


Figure 4 . Electrode setup for BD and PD measurement

## 2.4 Dielectric Strength Measurements

The dielectric strength test was conducted with alternating voltage, which should be increased from zero to the breakdown value. The voltage was applied to the samples by means of a high voltage transformer. The value of the voltage at which breakdown occurs in the sample was noted.

# 3. RESULTS

## 3.1 Analysis of Nano-scale Structure

Figure 5, 6, 7 and 8 shows the SEM analyzed image results. These results show that particles were in the form of nano metric range. The sizes of the particles were in the range from 50 to 120 nm size.

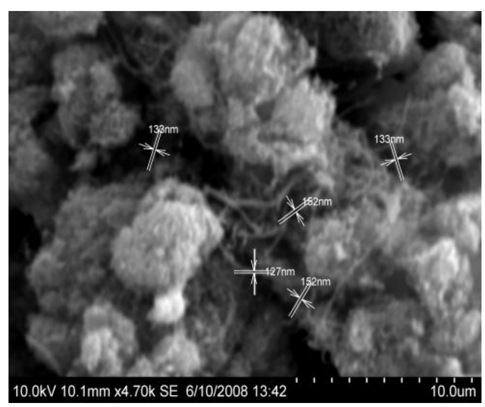


Figure 5. SEM analysis of CNT

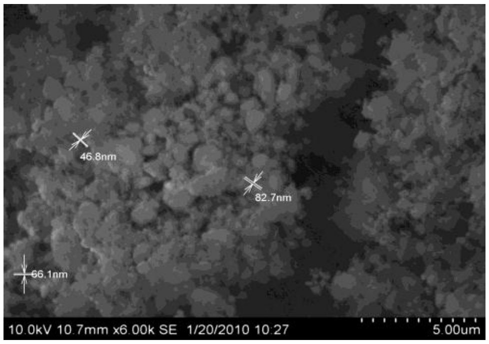


Figure 6. SEM analysis of $Al_2O_3$

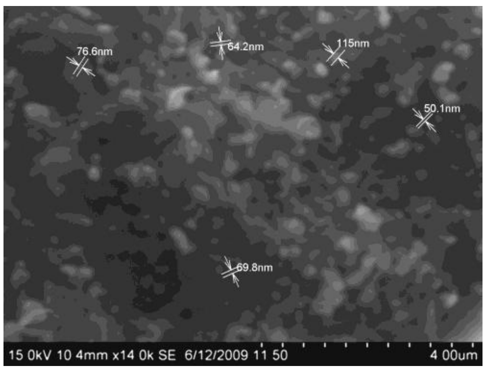


Figure 7. SEM analysis of $ZrO_2$

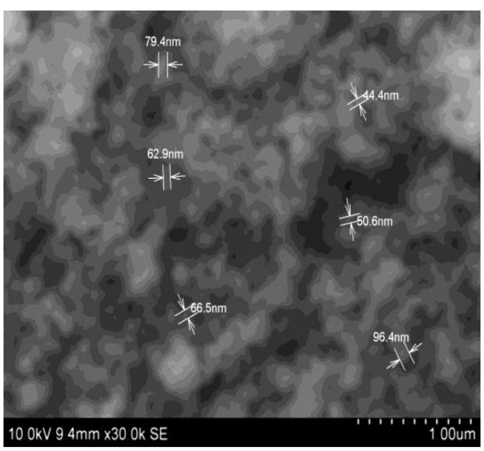


Figure 8. SEM analysis of ZnO

## 3.2 Partial Discharge Measurement

Partial discharges were in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. The partial discharge measurement was carried out in uniform field electrode configurations. The different values of PD inception and extinction voltage for uniform field configurations were shown in table 1.

**TABLE 1. Inception and Extinction Voltages**

| Sample | Inception voltage (kV) | pC | Extinction voltage (kV) | pC |
|---|---|---|---|---|
| Pure Enamel | 4.74 | 55 | 4.10 | 1.3 |
| 1wt% of CNT filled enamel | 3.20 | 65 | 2.29 | 1.4 |
| 3wt% of CNT filled enamel | 4.21 | 62 | 3.73 | 1.4 |
| 5wt% of CNT filled enamel | 4.31 | 66 | 3.73 | 1.4 |
| 1wt% of $ZrO_2$ filled enamel | 5.6 | 40 | 4.6 | 1.2 |
| 3wt% of $ZrO_2$ filled enamel | 5.2 | 35 | 4.4 | 1.3 |
| 5wt% of | 5.1 | 33 | 4.2 | 1.1 |

| | | | | |
|---|---|---|---|---|
| $ZrO_2$ filled enamel | | | | |
| 1wt% of $Al_2O_3$ filled enamel | 5.1 | 66 | 4.13 | 1.1 |
| 3wt% of $Al_2O_3$ filled enamel | 6.5 | 63 | 4.62 | 1.3 |
| 5wt% of $Al_2O_3$ filled enamel | 5.3 | 68 | 4.2 | 1.4 |
| 1wt% of ZnO filled enamel | 5.01 | 55 | 4.1 | 1.2 |
| 3wt% of ZnO filled enamel | 4.9 | 56 | 3.9 | 1.3 |
| 5wt% of ZnO filled enamel | 4.7 | 58 | 3.6 | 1.1 |

From the results, it is clear that the 3wt% of $Al_2O_3$ filled enamel sample has higher inception and extinction voltages.

### 3.3 Dielectric Strength Measurement

The breakdown voltage shows an increasing dependence on the nature and smoothness of the electrode material. The breakdown field strength was an extraordinary important material property for dimensioning an insulation system. The values of breakdown strength for different samples under uniform field configuration were shown in table 2. The 1wt% of $ZrO_2$ filled enamel sample has higher value of breakdown strength when compared to other samples.

**TABLE 2. Breakdown Strength for Various Samples at Uniform Field Configuration**

| Sample | Breakdown strength (kV/mm) |
|---|---|
| Pure Enamel | 2.56 |
| 1wt% of CNT filled enamel | 1.91 |
| 3wt% of CNT filled enamel | 2.34 |
| 5wt% of CNT filled enamel | 2.35 |
| 1wt% of $ZrO_2$ filled enamel | 3.78 |
| 3wt% of $ZrO_2$ filled enamel | 3.48 |
| 5wt% of $ZrO_2$ filled enamel | 3.03 |
| 1wt% of $Al_2O_3$ filled enamel | 3.26 |
| 3wt% of $Al_2O_3$ filled enamel | 3.41 |
| 5wt% of $Al_2O_3$ filled enamel | 3.13 |

| | |
|---|---|
| 1wt% of ZnO filled enamel | 3.61 |
| 3wt% of ZnO filled enamel | 3.51 |
| 5wt% of ZnO filled enamel | 3.48 |

## 4. CONCLUSIONS

SEM analysis showed that the prepared carbon particles were appearing in the form of nano metric size. This comparative study suggests the following results:

1. The 3wt% of $Al_2O_3$ filled enamel sample has higher inception and extinction voltages.
2. The 1wt% of $ZrO_2$ filled enamel sample has higher value of breakdown strength.

These results show that the additions of few weight percentages of nanofillers would improve the dielectric behaviour of the enamel. Similarly, this kind of study can be done for the enamel filled with various nanofillers at different proportions. Similarly these analyses can be made possible for other various nanofillers.

## 5 ACKNOWLEDGEMENT

The authors express their sincere gratitude to the Almighty God, Lord Jesus and Division of High Voltage Engineering, Anna University, Chennai, India for the sample preparation and testing of samples.

## 6. REFERENCES

1. Guoqin Zhang, et al, 2005 “Study of Nano TiO2 Filler in the Corona -resistant Magnetic Wire Insulation Performance of Inverter-fed Motor”, Proceedings of international Symposium on Electrical Insulating Materials.
2. Guastavino, et al, 2007, “Characterization of nanofilled epoxy varnish subjected to surface partial discharges”, IEEE Annual Report Conference on Electrical Insulation and Dielectric Phenomena.
3. Hulya Kirkici, Mert Serkan, Koppisetty. K, 2005 “Nano-dielectric Materials in Electrical Insulation Application”, IEEE.
4. Inuzukal. K, Inanol. H, Hayakawal. N, 2006 “Partial Discharge Characteristics of Nanocomposite Enameled Wire for Inverter-Fed Motor”, Annual Report Conference on Electrical Insulation and Dielectric Phenomena.
5. Masahiro Kozako, Norikazu Fuse, Yoshimichi Ohki, 2004 “Surface Degradation of Polyamide Nanocomposites Caused by Partial Discharges Using IEC Electrodes”, IEEE Transactions on Dielectrics and Electrical Insulation Vol. 00, No. 00.
6. Naoki Hayakawa, Hitoshi Okubo, 2008 “Lifetime Characteristics of Nanocomposite Enameled Wire under Surge Voltage Application”, IEEE Electrical Insulation Magazine.
7. Nguyen et al, 2009 “Investigations on Dielectric Properties of Enameled Wires with Nanofilled Varnish for Rotating Machines Fed by Inverters”, IEEE Electrical Insulation Conference.
8. Pugazhendhi Sugumaran. C, Mohan M.R, and Udayakumar. K, 2010, “Investigation of Dielectric and Thermal Properties of Nano-filler (ZrO2) Mixed Enamel”, IEEE Transaction on Dielectrics and Electrical Insulation, Vol.17, No.6.
9. Takahiro Imai, et al, 2006, “Effects of Nano- and Micro-filler Mixture on Electrical Insulation Properties of Epoxy Based Composites”, IEEE Transactions on Dielectrics and Electrical Insulation Vol. 13, No. 1.
10. Takahiro Imai, et al, 2008 “Improving Epoxy-based Insulating Materials with Nano-fillers toward Practical Application”, IEEE.
11. Takahiro Imai, et al, 2008 “Nano- and Micro-filler Combination Enabling Practical Use of Nanocomposite Insulating Materials”, Proceedings of international Symposium on Electrical Insulating Materials.
12. Edison Selvaraj. D, Pugazhendhi Sugumaran. C and SivaPrakash. A, “Characterization of Electrical and Thermal Properties of Enamel Filled with Carbon Nanotubes”, PEIE 2012, LNEE, pp. 496-502, 2012.
13. Edison Selvaraj. D and SivaPrakash. A, “Analysis of Dielectric Characteristics of Alumina Nano Filler Mixed Enamel”, proceedings of First International Conference On Engineering, Technolgy and Management - (ICETM'2012) organized by Rajiv Gandhi College of Engineering and Technology, Puducherry, India, pp. 87-91, 20012.