Dielectric Properties of Epoxy based Nanocomposites for High Voltage Insulation

G. Iyer[1], R. S. Gorur[1], R. Richert[2]
[1]School of Electrical, Energy and Computer Engineering
[2]Department of Chemistry and Biochemistry
Arizona State University
Tempe, AZ 85287, USA

A. Krivda and **L. E. Schmidt**
ABB Corporate Research, Baden-Daettwil, Switzerland

ABSTRACT

Epoxy polymer with micro, nano and micro + nano silica fillers have been evaluated for their electrical performance in high voltage insulation applications. The dielectric strength of these samples was measured in accordance with the ASTM D-149 standard. Dielectric spectroscopy was used to understand the role of space charge and interfaces in these materials. The results of dielectric spectroscopy suggest that significant improvement in the electrical performance can be expected by using samples containing nanofillers and micro + nanofillers when compared to materials containing only microfillers. However, the dielectric strength measurement showed no statistically significant improvement for the nanofilled samples. Techniques other than dielectric breakdown may be required to adequately characterize differences in the electrical performance of the dielectrics. For example, a partial discharge test using a highly non-uniform field may be more useful as it would correspond to simulate actual service conditions.

Index Terms — **Epoxy nanocomposites, nanofillers, nanodielectrics, microcomposites, permittivity, loss tangent, dielectric strength, breakdown.**

1 INTRODUCTION

CYCLOALIPHATIC epoxy resins have been used for indoor, outdoor and enclosed apparatus. They are mainly used for low and medium voltage (LV and MV) applications such as pin and post type insulators, bushings, instrument transformers for current and voltage measurement, bus support assemblies, switching and protection equipment applications [1, 2]. They were first introduced in the 1960's and their formulations and manufacturing processes have evolved continuously to the present state where high quality products can be cast economically. They have several advantages over porcelain such as light weight, easy to mold into complicated shapes, superior impact and seismic resistance. They also have the advantage that the same material (epoxy) fulfils the electrical and mechanical functions. Thus, interfacial issues that are commonly the origin of problems in devices that employ different materials like in composite insulators (fiber glass core and elastomer housing) are eliminated. Epoxy insulated devices also eliminate oil and problems associated with leakage and maintenance.

The use of inorganic fillers such as silica, alumina, etc. in polymeric materials has been done for many years. Addition of these fillers in the formulation reduces cost, improves fire resistance and mechanical properties like tensile strength. For outdoor applications, they enhance resistance to dry band arcing and surface discharges. The size of the fillers is in the range of 15-100 μm. Extensive research has been conducted to study the influence of micro-sized fillers on the electrical performance of epoxy materials for HV equipment [3, 4].

Over the last few years, there has been increased interest in the use of nano-sized fillers as additives to polymer materials (nanocomposites) [5, 6]. Electrical insulation using nanocomposites may provide superior performance when compared with conventional microfilled materials, such as lower dielectric losses and increased dielectric strength, tracking and erosion resistance, and surface hydrophobicity [7-9]. Such improvements can create apparatus that are more compact and last longer than what is available presently. Conflicting results on the performance of nanocomposite fillers have been reported and the underlying mechanisms are not adequately understood [10-14]. This is due to the fact that it is not easy to prepare samples containing nano-sized fillers. Uniform dispersion of the nanofillers in the polymer matrix is essential to realize the above stated benefits. For all of the above mentioned reasons, experiments were conducted on epoxy samples containing different concentrations of nano and micro + nano-sized fillers.

Manuscript received on 6 December 2010, in final form 23 February 2011.

2 SAMPLES EVALUATED

The samples that were evaluated are listed in Table 1. They were prepared by ABB Corporate Research, Switzerland. The samples were in the form of flat sheets of dimensions 75 mm × 75 mm × 1 mm thick. Anhydride curing cycloaliphatic epoxy resin system was used as the base. The micro-sized silica filler was irregularly shaped, epoxy silane treated and of an average size of 16 µm. The filler was dried overnight at 80 °C before casting. Nano-sized silica filler was of spherical shape with a diameter of about 20 nm and was supplied as a 40%wt master-batch by Nanoresins AG, Germany. Standard mixing, degassing, casting, curing and post-curing procedures were used to manufacture the samples. Prior to any testing at Arizona State University, the samples were heated in an oven for 20 hours at 160ºC to remove the absorbed moisture from the samples. It should be noted that even longer times (several days) may be needed to remove the excess moisture in some samples.

Table 1. Samples Evaluated.

Sample Number	Filler concentration (wt %)	Identification in figures
1	65% Micro	65% M
2	62.5% Micro + 2.5% Nano	62.5% M + 2.5% N
3	60% Micro + 5% Nano	60% M + 5% N
4	65% Micro + 5% Nano	65% M + 5% N
5	5% Nano	5% N
6	0% (Unfilled)	0%
7	2.5% Nano	2.5% N

3 SCANNING ELECTRON MICROSCOPY (SEM)

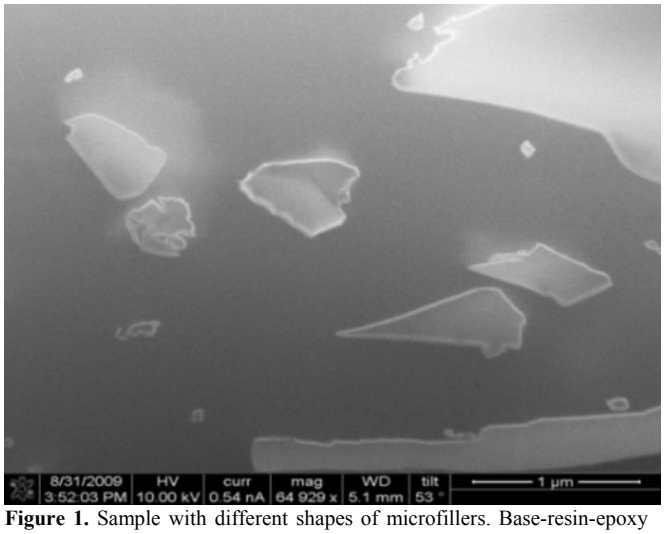

Figure 1. Sample with different shapes of microfillers. Base-resin-epoxy with 65% micro-sized silica filler.

Scanning Electron Microscopy was performed to check the dispersion of the filler material. The samples were cut into small pieces and were mounted on a stub. A thin coating (20 µm × 3 µm × 1 µm) of platinum was deposited on the surface. The platinum coating was done to protect the surface from damage while cutting into the sample. A gallium ion beam was used to trench into the material thereby revealing the fillers and their dispersion in the matrix. Figure 1 shows the micro-sized fillers of different shapes. Energy dispersive X-ray analysis (EDAX) was carried out at different locations on the surface confirming the filler to be silica.

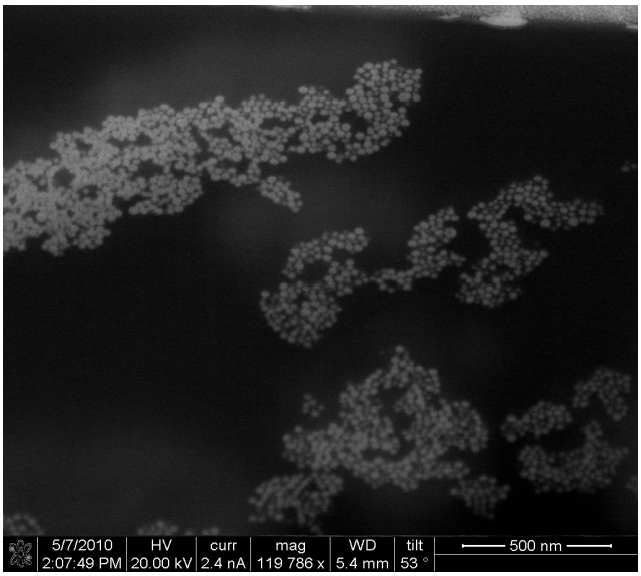

Figure 2. Sample containing agglomerated nano-sized silica fillers (10% nano). This sample was manufactured from a different kind of epoxy than all the other samples evaluated.

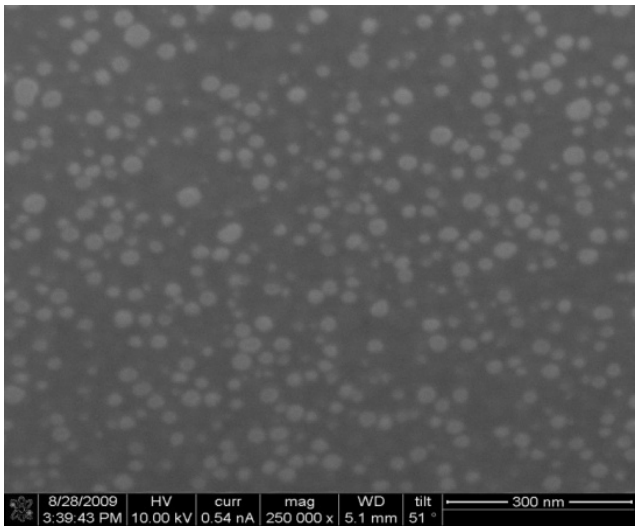

Figure 3. Sample showing uniformly dispersed nanofillers. Base-resin-epoxy with 65% micro-sized silica fillers and 5% nano-sized silica fillers.

Samples containing nanofillers are not easy to prepare as they have a tendency to agglomerate and form large clusters as shown in Figure 2. So, it is important to ensure uniform dispersion of the nanofillers in order to avoid such cluster formulation. This problem can be solved by using liquid dispersions (master-batches) provided by nanofiller suppliers. Figure 3 shows a picture of a well dispersed nanofilled sample. All the samples that are reported in this paper had well dispersed nanofillers. To understand the advantages that the nanofillers may provide over their