# Abstract

Insulation based on epoxy resin is widely used in high voltage applications. This project studies the formulation of epoxy based Nano composites and influence of Nano filler on the dielectric strength.Based material for all the samples is conventional bisphenol-A/epichlorohydrin derived liquid epoxy resin with anhydrite hardener. Filler materials are usedgraphene oxide and silicon dioxide.Silicon dioxide is widely used as filler for electrical applications since they improve mechanical, thermal and electrical properties, beside neat epoxy samples, which have been used as reference. Different combinations of epoxy resin Nano-composites were fabricated by using different Nano materials in order to test the electrical and mechanical properties of the new material to test the suitability of using the fabricated materials in high voltage insulations. Main intension of this project is to improve the dielectric strength of the base material with the use of optimum Nano material composition.

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# Chapter 1

## 1. Introduction

The Globally increasing demand of energy is a technical challenge for the electrical power generation, transmission and distribution system. This requires often contradictory features such as increasing voltage levels in combination with more compact designs in urban environments. This leads to an increased electrical stress on insulated systems. Since the Nano technology is a vastly developing field at present different types of research is conducting to improve the condition of current dielectric materials and replace them with Nano materials with high dielectric constant and low loss. Epoxy based insulation is widely used in electrical engineering e.g. for transformers, rotating machines, bushings or cable termination. It has excellent dielectric and mechanical properties, chemical stability and can be shaped into any form necessary. The scientists have been turned to find different types of composites by using Nano materials which will improve the properties of those which are used as conventional dielectric materials. There are different types of conventional high voltage insulating materials like glass, porcelain and ceramic. By using these materials mainly there have been made pin type and post type insulators.

Mostly epoxy is used for manufacturing high voltage maintenance tools and pin type insulators. So what I am basically trying to do is that by using different types of Nano materials (a material where the particle size is less than 100 nm) fabricating different samples by mixing different Nano material compositions (by w/w %) with the base epoxy material. The main focus of this project is to improve the dielectric strength of the fabricated samples and find the optimum composition of Nano particles which gives the highest dielectric breakdown strength.

## 1.1 Scope and Objectives

This project is basically concentrating on how to improve the dielectric breakdown strength and find the optimum composition where the highest dielectric breakdown strength occurs. And also I am considering particle distribution of the newly fabricated samples their permittivity values and the tan delta values as well. And also to simulate an epoxy insulator by using "ANSYS Maxwell" software to implement the electric field inside the insulator and the voltage distribution of the insulator, which will be helpful for commercializing the new fabricated materials as high voltage insulating materials with an economical basis.

### 1.2 Outline of the report

Firstchapter of this report includesa basic introduction to the project including the objective and scope. The second chapter basically gives an idea about the literature survey. And from their onwards discuss a comprehensive detailed note of fabricating process, mold designing, tests conducted, data analysis, conclusions and finally about the future work as well.

# Chapter 2

### 2. Background Study and Literature Review

I had to do lot of research in order to come up with a clear process because the Nano technology filed is still at developing stage. Under this i mainly considered to find out what types of materials are being used to manufacture high voltage insulators other than the conventional materials. Then the next challenge was to find out suitable Nano materials as fillers. Therefore i was referred lot of research papers to come up with suitableNano fillers to improve the dielectric breakdown strength of the base materials. Then after selecting suitable Nano materials the next challenge was fabricating different samples with different Nano material compositions. The fabricating process is a complex process which requires lot of time. Then i had to perform some tests in order to check the success of the process. After that analyses the data, mainly the test results by using different techniques as said in technical papers and the standards to validate our final outcome.

### 2.1 Material Selection

Literaturesurvey showed that epoxy is the most commonly used material in high voltage insulator manufacturing other than the conventional materials. It has disrupted sp2 bonding orbitals and abundant surface groups. Therefore it has very good electrical insulating and dielectric properties. In the category of epoxy also there is a special group as Cycloaliphatic Epoxy resins; these are the resins which are used for molding purposes. The particular epoxy resin was used EPON828 and the hardener was Curing Agent 3388.

When applies Nano sheets to the epoxy it reduces the conductivity of the polymer by blocking iron transport therefore no electric current passing through the Nano network. Out of mostcommonlyused Nano fillers i wasselected graphene oxide (GO) and silicon dioxide for my research. Graphene oxide (GO) is commonly prepared from natural flake graphite by the hummers method and serve as an intermediate product to prepare graphene. In this research I was used GO prepared from natural Sri Lankan graphite and Silicon dioxide (15 nm) Nano particles which was imported from Canada.

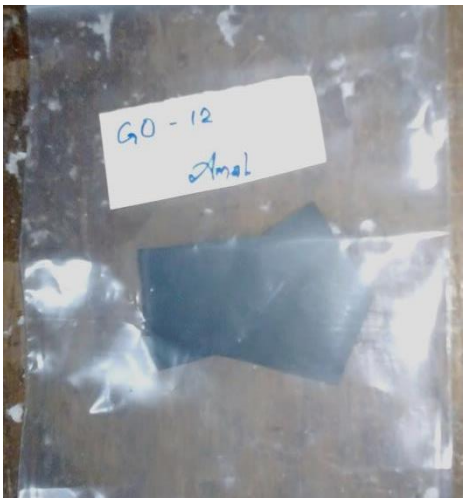



**Figure1.1: Graphene oxide**

**Figure1.2: Silicon dioxide Nano powder**

## 2.2 Fabricating process

The fabricating process was conducted according to a standard process which i was come across in my literature review. Mold designing was also conducted according to the standard sample size. Number of samples from one composition was also selected according to the standards. Initially graphene oxide (GO12) Nano composites were fabricated and then moved to fabricate silicon dioxide and graphene oxide / silicon dioxide Nano composites.

## 2.3 Tests to be performed

Before the breakdown test first test should be the Scanning Electron Microscope test (SEM test) to identify the Nano particle distribution. Then the Breakdown test according to the standard procedures. I used eight samples from each composition (according to the ASTM D-149) to test the breakdown strength. Then for our simulations we need the permittivity and the tan delta values of each sample. So we check the capacitance of a small piece of each sample by using the "LCR Meter" and calculated the permittivity and tan delta values.

## 2.4 Data Analysis

According to the literature review the breakdown data can be analyzed by using different types of distributions as Poison distribution, Normal distribution, Weibull distribution and etc. But as an empherical methods Weibull distribution is being used most commonly and it gives the correct mean value of a data set when it comes to failure analysis test data. Permittivity and tan delta values also analyzed properly.

## 2.5 Simulations

Simulation was conducted by using the "ANSYS Maxwell" software by using the calculated permittivity and tan delta values. Electric field inside and outside the epoxy insulator and the Voltage distribution along the surface of the insulator is implemented in the simulation and compared them with each composition.

# Chapter 3

## 3. Sample Fabrication

### 3.1 Mold Designing

A mold which is required for casting of epoxy Nano-composite mixture was decided to design with metal because of the higher durability as well as the polish surface texture which helped to eject samples from the mold easily. For the dielectric breakdown testing purpose of Nano-composite samples, it was needed to fabricate them with 1 mm thickness. Therefore the mold cavity had to be in 1 mm depth. The area of the sample was decided to produce with 75 mm x 75 mm. Therefore altogether the mold cavity was produced with 75 mm x 75 mm x 1mm.

The mold was designed with 1 mm thickness zinc coated steel sheets. Two square shape pieces of 100 mm x 100 mm were cut using a metal sheet cutting machine. In one of them, 75 mm x 75 mm square shape piece was removed using a grinder. Then two pieces were aligned and marked points for drilling. After that 12 holes were drilled around the cavity which was used to put bolts. 12 number of 6 mm bolts were used to fit the two metal pieces.

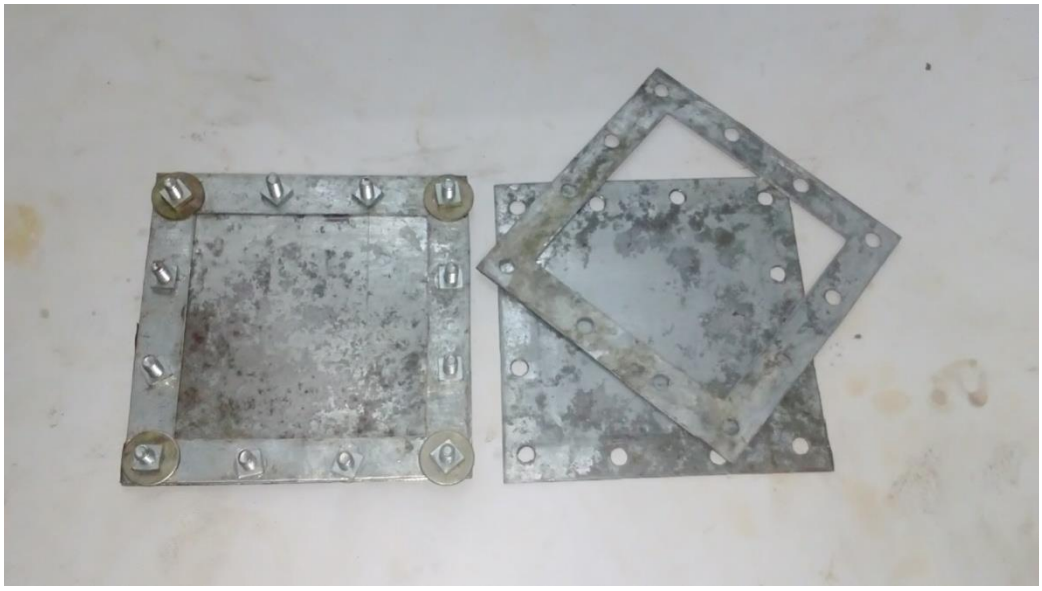


**Figure 3.1: Designed mold**

Finally, a very thin silicon oil layer was applied inside the mold cavity because it acted as a lubricant between the mold and the epoxy sample as well as it did not mix or react with the epoxy mixture. It helped to eject samples from the mold easily.

### 3.2 Fabrication Process of Nano-composite Samples

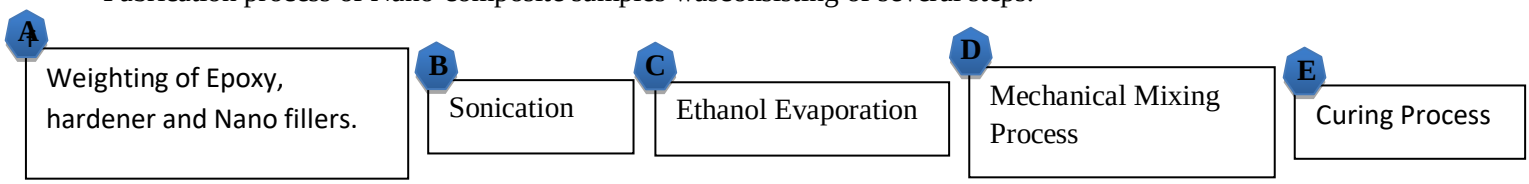
EPON 828 epoxy resin and Curing Agent 3388 was used as the base material. Silicon Oxide Nano fillers (15-20 nm) and Graphene Oxide Nano fillers (200-500 nm) were used as the filler materials.

| Graphene oxide Nano compositions (w/ w %) | Silicon dioxide Nano compositions (w/w %) | Graphene dioxideandSilicon oxide (w/w %) |
|---|---|---|
| 0.05 | 0.05 | 0.05 |
| 0.1 | 0.1 | 0.1 |
| 0.5 | 0.5 | 0.5 |
| 1 | 1 | 1 |
| 2 | 2 | 2 |
| | | |
| | | |

**Table 3.1: Nano-composites Combinations**

There were two samples (75 mm x 75mm x 1mm) for each composition and cut into 4*2 = 8 pieces for testing purpose.

Fabrication process of Nano-composite samples wasconsisting of several steps.



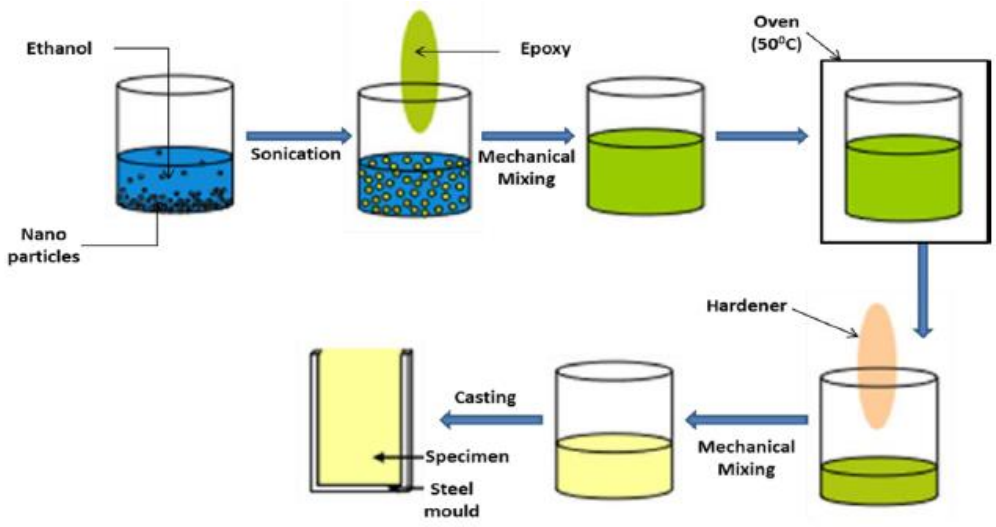




**Figure 3.2: Fabrication process of epoxy Nano-composite sample**

### 3.2.1 Measuring Process of Epoxy, hardener and Nano fillers

Epon 828 epoxy resin and curing agent 3388 should be mixed in 3:2 volume ratios. After calculating required volumes of two mold cavities, required volume of epoxy to hardener was chosen as 7.5 ml: 5 ml respectively. Therefore 7.5 ml volume of epoxy resin and 5 ml volume of curing agent were measured using a pipette and a measuring cylinder as shown in Fig.3.6.

**Figure 3.3: Measuring Epoxy resin Volume**


**Figure 3.4: Measuring Epoxy resin Weight**

Since the Nano fillers were added based on weight to weight ratio, it was required to measure both the epoxy weight and the Nano filler weight. Micro balance was used to measure Nano filler weights as shown in Fig.3.8. It gave the weight for four decimal places.

**Sample calculation for Graphene oxide 0.1 % (w/w)**

Weight of the empty measuring cylinder = 39.18 g

Weight of the measuring cylinder with epoxy = 49.06 g

Weight of the epoxy (M) = 49.06 – 39.18 g

= 9.88 g

Let say that required Silicon oxide weight (m)

$\frac{m}{M+m}$= 0.001

Therefore required Silicon oxide weight (m) = 9.88 mg

| Graphene oxide Nano compositions (w/ w %) | Graphene oxide (mg) |
|---|---|
| 0.05 | 4.94 |
| 0.1 | 9.88 |
| 0.5 | 49.4 |
| 1 | 100.82 |
| 2 | 201.63 |
| | |
| | |

**Table 3.2: Nano-composites Combinations**

| Silicon dioxide Nano compositions (w/w %) | Silicon dioxide (mg) |
|---|---|
| 0.05 | 4.94 |
| 0.1 | 9.88 |
| 0.2 | 19.76 |
| 0.5 | 49.4 |
| 1 | 100.82 |
| 2 | 201.63 |

**Table 3.3: Nano-composites Combinations**

| Graphene dioxide and Silicon oxide (w/w %) | Graphene oxide (mg) | Silicon dioxide (mg) |
|---|---|---|
| GO 0.2%,SiO2 0.01% | 10 | 0.98 |
| GO 0.5%, SiO2 0.01% | 50 | 0.98 |
| | | |
| | | |
| | | |
| | | |
| | | |

**Table 3.3: Nano-composites Combinations**


**Figure 3.5: Measuring Nano filler weight**

### 3.2.2 Sonication

Samples containing Nano fillers are not easy to prepare as they have tendency to agglomerate and form large clusters so, it is important to ensure uniform dispersion of the Nano fillers in order to avoid such cluster formation. Therefore to disperse the Nano particlesuniformly throughout the epoxy mixture I was used a special process call sonication which was generally used to disperse the Nano particles. Nano fillers are required to be submerged inside a medium during the sonication process. That medium could be Ethyl alcohol (Ethanol) or water. Then this medium should be evaporated before adding the epoxy resin. Since ethanol could be evaporated easily than water, ethanol was used as the medium for sonication in this project. 5-6 ml volume of ethanol was measured and put into a test tube. Then measured Nano filler was added to the ethanol medium as shown in Fig.3.9. The test tube should be put into an ultra-sonic cleaner for sonication. Ultra-sonic cleaner is a special kind of equipment which filled with water. Ultra-sonic wave having the frequency of 20 kHz was generated and the test tube was subjected to the ultra-sonic wave while partially submerging inside the water as shown in Fig.3.10. For 30 minutes. After that the Nano sample was added to the beaker which was contained measured epoxy resin and the beaker was kept on Hotplate Magnetic Stirrer for magnetic stirring.

**Figure 3.7: Sonication process inside an ultra-sonic cleaner**

**Figure 3.8: Adding sonicated Nano fillers to Epoxy resin**

### 3.2.3 Ethanol Evaporation

The next step was to evaporate ethanol from the medium. The beaker was kept inside fume hood onhotplate magnetic stirrer for a period of 2-3 hours at 50 $C^0$ to evaporate ethanol. Since the boiling point of ethanol is 78 $C^0$, it was important to avoid the boiling of ethanol for eliminate air bubbles. Therefore the temperature should be well below the boiling temperature. After evaporation of ethanol, the mixture should be kept at room temperature for 30 minutes to cool down to room temperature before adding the hardener.

**Figure 3.9: Evaporation of ethanol inside fume hood**

Measured curing agent volume was added to the epoxy-Nano filler mixture. Then the mixture should be mixed well for a period of 15 minutes using a glass rod. Mixing process should be done very carefully by avoiding formation of air bubbles. Also Nano particles inside the mixture reduced the formation of air bubbles. When air bubbles were present in the mixture, voids might be formed inside the samples. Hence the dielectric breakdown might occur at a lower voltage than the expected voltage due to partial discharge.

**Figure 3.10: Adding Hardener**

**Figure 3.11: Mixing process of GO composite**

**Figure 3.12: Mixing process of silicon dioxide Nano composite**

### 3.2.5 Curing Process

Epoxy mixture should be poured into the mold very carefully and equally throughout the mold cavity. Formation of air bubbles should be avoided during the pouring. After that, the mixture should be allowed to solidify for about two days. Then the sample could be ejected from the mold by losing the nuts and bolts. After that the samples should also be kept in room temperature for about two weeks to dry them completely.

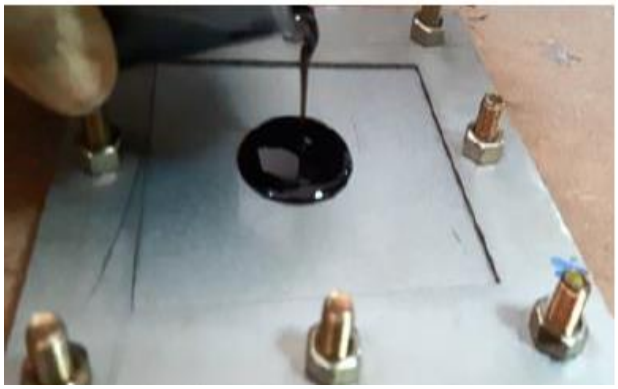


**Figure3.14: Spreading the mixture**

**Figure3.15: Settling the mixture**

### 3.2.6 Fabricated Samples

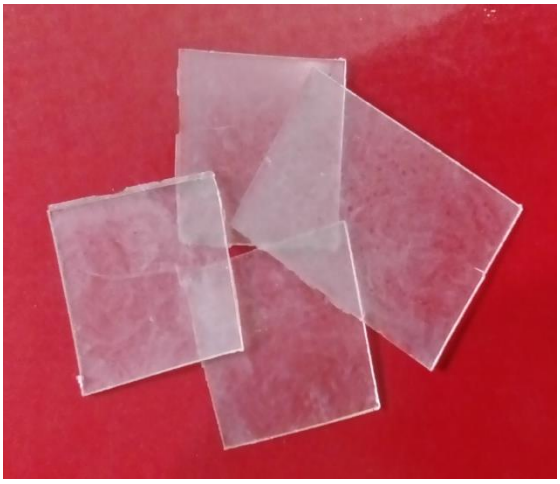


**Figure 3.16: Pure Epoxy Sample**

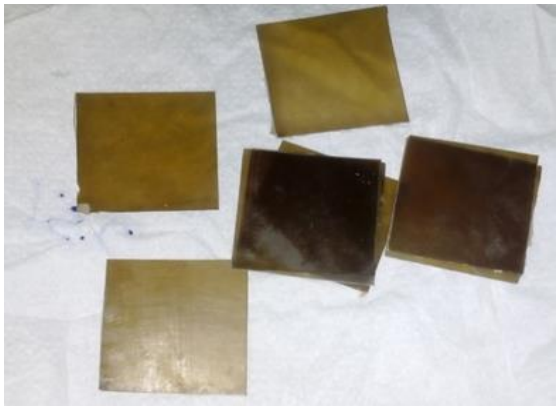


**Figure 3.17: 1% Graphene Oxide Nano-composite**

**Figure 3.18: 0.2 % Silicon dioxide Nano-composite**

# Chapter 4

## 4. Testing procedures

High-voltage testing utilizes the phenomena in electrical insulations under the influence of the electric field for the definition of test procedures and acceptance criteria. The phenomena e.g., breakdown, conductivity and dielectric losses depend on the insulating material, on the electric field generated by the test voltages and shaped by the electrodes as well as on environmental influences. Considering the phenomena, this chapter describes the common basics of HV test techniques including Di-Electric Breakdown test, loss tangent test and the SEM (scanning electron microscope) test. All the details related to the mentioned tests are considered in this Chapter.

## 4.1 Dielectric Breakdown Test

The dielectric strength of an electrical insulating material is a property of interest for any application where an electrical field is present. In many cases the dielectric strength of a material will be the determining factor in the design of the apparatus in which it is to be used.

When an electrical insulation is stressed in the electric field, ionization causes electrical discharges which may grow from one electrode of high potential to the one of low potential or vice versa. This may cause a high current rise, i.e. the dielectric losses its insulation property and thus its function to separate different potentials in an electric apparatus or equipment. This phenomenon shall be called ‘‘breakdown’’ related to the stressing voltage. The voltage gradient at which dielectric failure of the insulating material occurs under specific conditions of test is called dielectric strength of the tested material.

Since main scope of this project was to increase the di- electric breakdown voltage of a Nano-filled epoxy based insulating composite, the di-electric breakdown test was the major test in the testing procedure. By considering the standards for the high voltage testing and the accuracy of the readings of the voltages the breakdown tests were conducted in power system lab at University of Moratuwa. Powersystem laboratory apparatus gives the value of maximum 60 k V for this test only about 30-50 kV as breakdown voltages enough.

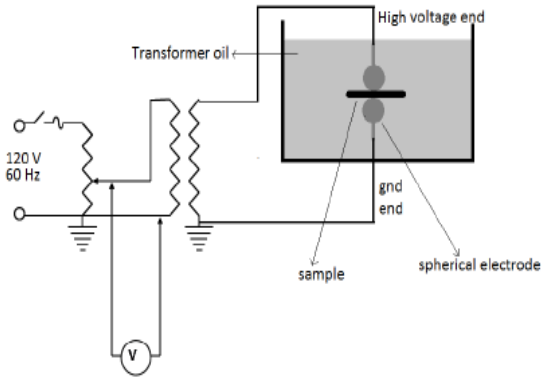



**Figure 4.1: Schematic diagram of Dielectric breakdown test**

### 4.1.1 Standards for High Voltage Testing

To obtain the Dielectric strength of solid electrical insulating materials testing was conducted in accordance with ASTM D 149 using the set up shown in figure 4.1.1. The samples were used sheets of dimensions 37.5 mm × 37.5 mm × 1 mm. This test method is most commonly used to determine the dielectric breakdown voltage through the thickness of a test specimen (puncture).

### 4.1.2 Voltage Source

To obtain the test voltage from a step up transformer supplied by from a low voltage source is provided by the apparatus. The maximum attainable voltage is 60 kV. This is a test set with motor-driven voltage control. Also the capacity of the source (60 kV) was sufficient to maintain the test voltage until dielectric breakdown occurs. And the voltage source is equipped with a circuit breaking device to protect by disconnecting from the power source and protect it from overload as a result of specimen breakdown causing an overload of the testing apparatus. Also there is a mechanism to retain the maximum applied test voltage of the meter after the breakdown So that the breakdown voltage can be accurately read and recorded.

### 4.1.3 Electrodes

Since the dielectric breakdown voltage vary depending upon the geometry and placement of the test electrodes, it is important that the most suitable and standard electrodes are used when the testing. In here we used the apparatus which have spherical electrodes 1 cmdiameter.

### 4.1.4 Surrounding Medium

The test apparatus was immersed in the transformer oil to avoid surface flashover and the effects of partial discharges prior to breakdown.

### 4.1.5 Safety

Since lethal voltages may be present in this test and electrically conductive parts that any person might come into contact with during test, the whole the conductive parts are earthed in this apparatus to ensure the safety. Also since there are induced charge during the test and after the test has done, all the conductive ends are earthed by use of earth rod.

### 4.1.6 Test Specimens

Since the specimen should be large enough to prevent the flash over phenomena before the breakdown occurs and by comparing electrodes diameters, the 37.5 mm x 37.5 mm square shape and 1 mm thickness samples are made by the cured sample.

**Figure 4.2: Positioning the test specimen**

Before carry out the standards dielectric breakdown test for specimens it was required to perform few breakdowns to specify the breakdown voltages. Theoil was stirred after every breakdown measurement and replaced after every 10 measurements so as to ensure that the readings were not affected due to the by-products of degradation.Also the electrodes were cleaned after every measurement.

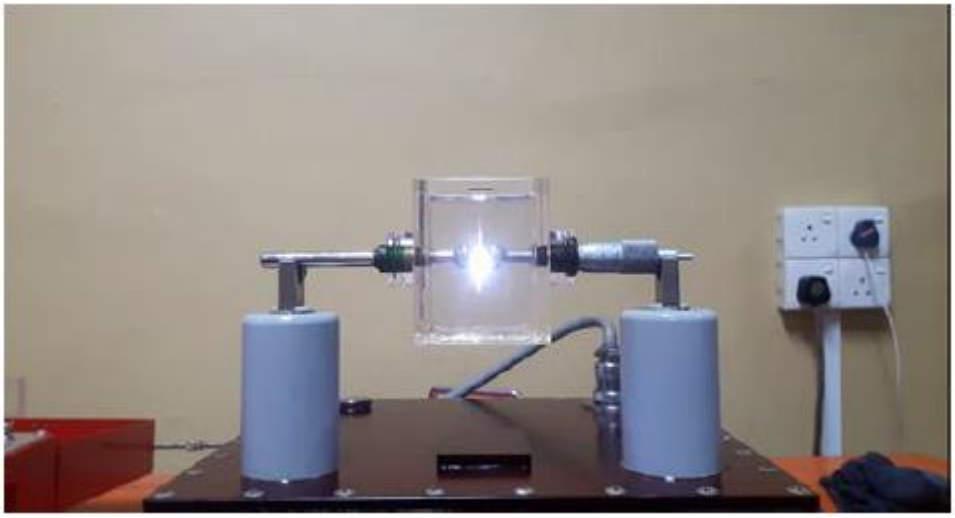


**Figure 4.3: Dielectric breakdown of an epoxy sample**

## 4.2 Scanning Electron Microscope (SEM) test

Scanning electron microscope (SEM) is an electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition.

To ascertain the degree of dispersion of the Nano fillers in the insulating materials, a SEM electron microscope system is used to analyze the morphology of the composites.The particle size distribution of the Nano fillers was analyzed by scanning electron microscopy (SEM). The dispersion of the Nano filler, as mentioned before, is very important in obtaining consistent properties in the Nano-composition.

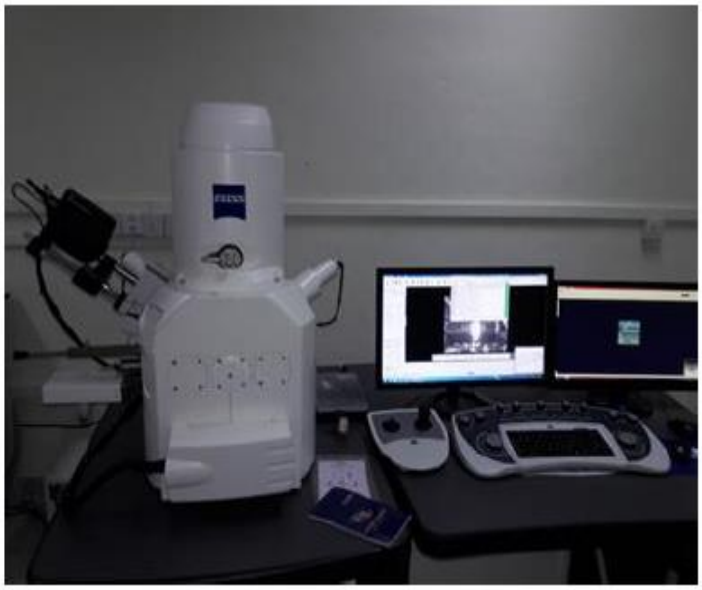


**Figure 4.4: Scanning Electron Microscope (SEM)**

**Figure 4.5: Quorum SC7620 Sputter Coater**

### 4.3.1 Procedure

- Extracting of the required part of the specimen:

Simply cut and pull the wanted part carefully away from the body.

- Cleaning:

The specimens coming in from the field are usually dirty and often we can hardly make out what the specimen looks like. So if we are to view the specimen under high magnification it must be totally clean.

- Drying:

It is essential that the specimen is completely dry. The SEM works under a vacuum and for an image to be derived the specimen must be dry, if not the specimen will simply collapse or even better, blow up in front of your eyes in the vacuumed chamber.

- Mounting:

The next step is to mount the specimen on an aluminum stub. The stub is often a small, flat, round piece of metal.

- Gold coating:

The gold splutter coater is a machine that we use to coat the mounted specimens in gold before they go into the SEM. The reason why we gold coat the specimens is because the SEM uses an electron beam instead of a light globe to illuminate the specimen. If the specimen is not finely covered with a metal like gold we will get a very poor signal thus the image derived will be very dark and perhaps not even there.

## 4.3 Permittivity and Tan Delta Test

### 4.2.1 Permittivity

The relative Permittivity of a material is the relation between the capacity of a capacitor which is filled with the material and the capacity of the same capacitor when vacuum is the dielectric.

### 4.2.2 Tan Delta (Dissipation Factor)

Tan Delta, also called Loss Angle or Dissipation Factor testing, is a diagnostic method of testing insulator to determine the quality of the insulation. This is done to try to predict the remaining life expectancy and in order to prioritize insulation replacement.

If the insulation is free from defects, like moisture and air pockets, etc., the insulation approaches the properties of a perfect capacitor. It is very similar to a parallel plate capacitor with the conductor and the neutral being the two plates separated by the insulation material. In a perfect capacitor, the voltage and current are phase shifted 90 degrees and the current through the insulation is capacitive. If there are impurities in the insulation, like those mentioned above, the resistance of the insulation decreases, resulting in an increase in resistive current through the insulation. It is no longer a perfect capacitor. The current and voltage will no longer be shifted 90 degrees. It will be something less than 90 degrees. The extent to which the phase shift is less than 90 degrees is indicative of the level of insulation contamination, hence quality/reliability. This “Loss Angle” is measured and analyzed.

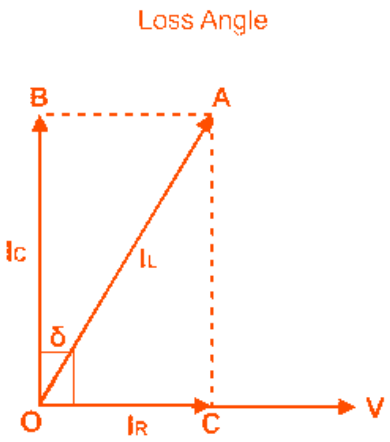



**Figure 4.6: Loss angle of ar**

For simulation purpose it is needed to measure the relative permittivity and loss tangent of the each and every different sample by a machine called LCR meter which was located in the laboratory at physics department. Since it does not give the relative permittivity straight, we had to measure the capacitance of the sample and by using capacitance equation relative permittivity is calculated. Tan delta or dissipation factor is calculated by after getting the delta value from the LCR meter.


**Figure 4.7: LCR Meter**

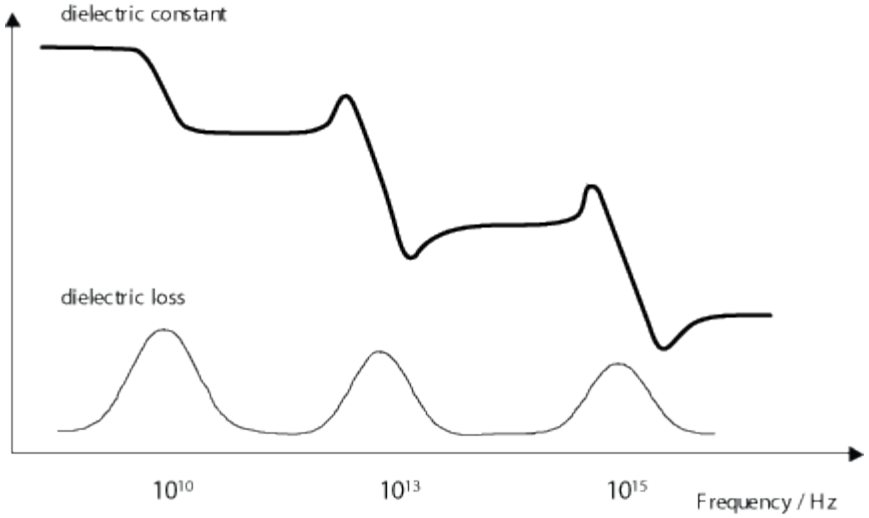



**Figure 4.8: Variation of dielectric loss and dielectric constant with frequency**

Before get the readings from the LCR meter testing sample is needed to prepare as a capacitor. For that two very thin metal sheets are attached to the two sides of the insulator sample.

These results are taken after testing with LCR meter. Relative permittivity was calculated by following equation.

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

Area and thickness of each sample are measured by using venire caliper and the micrometer shrew gauge. Loss tangent is taken after the reading of delta which is taken from LCR meter. Average thickness is taken by taking the thickness value from four different locations in the testing specimen.

# Chapter 5

## 5. Test results

After fabricating the Nano composites, it will be testedfor high voltage breakdown and permittivity. Then the results should be analyzed properly. Because those results could decide suitability of the Nano composites. During testing procedures following samples were being tested.

| Samples | Filler percentages(w/w%) |
|---|---|
| Pure epoxy | None |
| Graphene oxide(Nano) + Pure epoxy | GO 0.05%, 0.1%, 0.5%, 1%, 2% |
| Silicon dioxide(Nano) + Pure epoxy | SiO2 0.05%, 0.1%, 0.2%,0.5%, 1% |
| Graphene oxide(Nano)+ Silicon dioxide(Nano)+ Pure epoxy | GO 0.2%,SiO2 0.2% |
| Graphene oxide(Nano)+ Silicon dioxide(Nano)+ Pure epoxy | GO 0.2%,SiO2 0.01%<br>GO 0.5%, SiO2 0.01% |

**Table 5.1: Nano-composites Combinations**

### 5.1 High voltage breakdown test results

#### 5.1.1 Pure epoxy samples

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 38.5 | 1.04 | 36.981 |
| Sample 2 | 37.0 | 0.98 | 38.281 |
| Sample 3 | 37.0 | 1 | 37.322 |
| Sample 4 | 38.0 | 1.02 | 37.456 |
| Sample 5 | 37.5 | 0.98 | 38.564 |
| Sample 6 | 38.5 | 1.04 | 36.981 |
| Sample 7 | 37.0 | 0.97 | 38.341 |
| Sample 8 | 38.5 | 1.06 | 36.423 |

**Table 5.2: Breakdown test results of pure epoxy**

#### 5.1.2 Graphene oxide samples

Graphene oxide 0.05% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 41.5 | 1.02 | 40.69 |
| Sample 2 | 40.0 | 0.98 | 40.82 |
| Sample 3 | 42.5 | 1.04 | 40.87 |
| Sample 4 | 42.0 | 1.02 | 41.18 |
| Sample 5 | 39.0 | 0.95 | 41.05 |
| Sample 6 | 42.0 | 1 | 42.00 |
| Sample 7 | 41.0 | 0.98 | 41.84 |
| Sample 8 | 38.0 | 1.03 | 36.89 |

**Table 5.3: Breakdown test results of Graphene oxide 0.05% (w/w)+ pure epoxy**

Graphene oxide 0.1% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 45.5 | 1.14 | 39.91 |
| Sample 2 | 34.0 | 1.05 | 32.38 |
| Sample 3 | 42.5 | 1.13 | 37.61 |
| Sample 4 | 45.0 | 1.02 | 44.12 |
| Sample 5 | 39.0 | 0.98 | 39.80 |
| Sample 6 | 42.0 | 0.98 | 42.86 |
| Sample 7 | 44.0 | 0.97 | 45.36 |
| Sample 8 | 38.0 | 1.06 | 35.85 |

**Table 5.4: Breakdown test results of Graphene oxide 0.1% (w/w)+ Pure epoxy**

Graphene oxide 0.5% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 39.5 | 0.96 | 41.15 |
| Sample 2 | 40.0 | 0.98 | 40.82 |
| Sample 3 | 40.5 | 1.02 | 39.71 |
| Sample 4 | 40.0 | 1.02 | 39.22 |
| Sample 5 | 42.0 | 1.13 | 37.17 |
| Sample 6 | 40.0 | 1.04 | 38.46 |
| Sample 7 | 40.0 | 0.97 | 41.24 |
| Sample 8 | 42.5 | 1.15 | 36.96 |

**Table 5.5: Breakdown test results of Graphene oxide 0.5% (w/w)+ Pure epoxy**

Graphene oxide 1% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 40.5 | 1.15 | 35.22 |
| Sample 2 | 40.0 | 1 | 40.00 |
| Sample 3 | 40.5 | 1.16 | 34.91 |
| Sample 4 | 40.0 | 1.02 | 39.22 |
| Sample 5 | 40.0 | 0.98 | 40.82 |
| Sample 6 | 40.0 | 1.04 | 38.46 |
| Sample 7 | 40.0 | 0.96 | 41.67 |
| Sample 8 | 40.0 | 1.06 | 37.74 |

**Table 5.6: Breakdown test results of Graphene oxide 1% (w/w)+ Pure epoxy**

Graphene oxide 2% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 24.5 | 1.29 | 18.99 |
| Sample 2 | 23.5 | 1.36 | 17.28 |
| Sample 3 | 18.0 | 0.97 | 18.56 |
| Sample 4 | 20.5 | 1.02 | 20.10 |
| Sample 5 | 17.0 | 0.95 | 17.89 |
| Sample 6 | 21.5 | 1.04 | 20.67 |
| Sample 7 | 22.0 | 1.12 | 19.64 |
| Sample 8 | 21.5 | 1.06 | 20.28 |

**Table 5.7: Breakdown test results of Graphene oxide 2% (w/w)+ Pure epoxy**

### 5.1.3 Silicon dioxide samples

Silicondioxide 0.05% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 37.5 | 0.97 | 38.66 |
| Sample 2 | 34.0 | 0.96 | 35.42 |
| Sample 3 | 42.0 | 1.04 | 40.38 |
| Sample 4 | 37.5 | 1.02 | 36.76 |
| Sample 5 | 38.5 | 1.15 | 33.48 |
| Sample 6 | 42.0 | 1.04 | 40.38 |
| Sample 7 | 38.5 | 0.97 | 39.69 |
| Sample 8 | 40.5 | 1.15 | 35.22 |

**Table 5.8: Breakdown test results of Silicondioxide 0.05% (w/w)+ Pure epoxy**

Silicondioxide 0.1% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 45.5 | 1.04 | 43.75 |
| Sample 2 | 34.0 | 0.98 | 34.69 |
| Sample 3 | 42.5 | 1 | 42.50 |
| Sample 4 | 45.0 | 1.02 | 44.12 |
| Sample 5 | 39.0 | 0.98 | 39.80 |
| Sample 6 | 42.0 | 1.04 | 40.38 |
| Sample 7 | 44.0 | 0.97 | 45.36 |
| Sample 8 | 38.0 | 1.06 | 35.85 |

**Table 5.9: Breakdown test results of Silicondioxide 0.1% (w/w)+ Pure epoxy**

Silicondioxide0.2% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 43.0 | 1.26 | 34.13 |
| Sample 2 | 35.0 | 1.34 | 26.12 |
| Sample 3 | 44.5 | 0.97 | 45.88 |
| Sample 4 | 45.5 | 1.02 | 44.61 |
| Sample 5 | 41.0 | 0.94 | 43.62 |
| Sample 6 | 42.5 | 1.08 | 39.35 |
| Sample 7 | 44.5 | 1.12 | 39.73 |
| Sample 8 | 40.0 | 1.08 | 37.04 |

**Table 5.10: Breakdown test results of Silicondioxide 0.2% (w/w)+ Pure epoxy**

Silicondioxide0.5% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 39.0 | 1.24 | 31.45 |
| Sample 2 | 33.5 | 1.35 | 24.81 |
| Sample 3 | 44.0 | 0.98 | 44.90 |
| Sample 4 | 44.5 | 1.02 | 43.63 |
| Sample 5 | 39.5 | 0.94 | 42.02 |
| Sample 6 | 40.5 | 1.04 | 38.94 |
| Sample 7 | 42.5 | 1.12 | 37.95 |
| Sample 8 | 40.0 | 1.06 | 37.74 |

**Table 5.11: Breakdown test results of Silicondioxide 0.5% (w/w)+ Pure epoxy**

Silicondioxide1% (w/w)+ Pure epoxy

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | 42.0 | 0.96 | 43.75 |
| Sample 2 | 32.5 | 0.98 | 33.16 |
| Sample 3 | 42.5 | 1.04 | 40.87 |
| Sample 4 | 43.5 | 1.02 | 42.65 |
| Sample 5 | 38.0 | 1.15 | 33.04 |
| Sample 6 | 38.5 | 1.04 | 37.02 |
| Sample 7 | 41.0 | 0.98 | 41.84 |
| Sample 8 | 40.0 | 1.15 | 34.78 |

**Table 5.12: Breakdown test results of Silicondioxide 1% (w/w)+ Pure epoxy**

### 5.1.4 Graphene oxide(Nano) + Silicon dioxide(Nano) samples

Graphene oxide 0.2% (w/w) + Silicon dioxide 0.2% (w/w)

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | | | |
| Sample 2 | | | |
| Sample 3 | | | |
| Sample 4 | | | |
| Sample 5 | | | |
| Sample 6 | | | |
| Sample 7 | | | |
| Sample 8 | | | |

**Table 5.13: Breakdown test results of Graphene oxide 0.2% (w/w) + Silicon dioxide 0.2% (w/w)**

Graphene oxide 0.2% (w/w) + Silicon dioxide 0.01% (w/w)

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | | | |
| Sample 2 | | | |
| Sample 3 | | | |
| Sample 4 | | | |
| Sample 5 | | | |
| Sample 6 | | | |
| Sample 7 | | | |
| Sample 8 | | | |

**Table 5.14: Breakdown test results of Graphene oxide 0.2% (w/w) + Silicon dioxide 0.01% (w/w)**

Graphene oxide 0.5% (w/w) + Silicon dioxide 0.01% (w/w)

| Sample | Breakdown voltage(kV) | Thickness of sample(mm) | Breakdown strength(kV/mm) |
|---|---|---|---|
| Sample 1 | | | |
| Sample 2 | | | |
| Sample 3 | | | |
| Sample 4 | | | |
| Sample 5 | | | |
| Sample 6 | | | |
| Sample 7 | | | |
| Sample 8 | | | |

**Table 5.15: Breakdown test results of Graphene oxide 0.5% (w/w) + Silicon dioxide 0.01% (w/w)**

# Chapter 6

## 6. Analysis of results

### 6.1 Dielectric breakdown strength result analysis

In this analysis part I will be compare dielectric strength of the fabricated Nano composites were comparison with respect to pure epoxy sample. It can be clearly seen that fabricated samples thickness are not exactly 1mm. So I will do a linearization to get 1mm thickness breakdown strengths.

According to ASTM D149 standard for solid breakdown tests, it was found that at least 5 samples should be checked. Using only 5 samples it is not suitable for getting average values for above results. Therefore I was fabricated 8 samples for each composition. In literature review it was found that all the solid dielectric failure distribution behaves as a 'Weibull' distribution. So that was an empirical distribution. Using above breakdown strengths if we know the distribution we can get more accurate mean value.

In this Minitab software module, it created the Weibull distribution of failure analysis by using the values of above 8 samples of each composition. Using Minitab average values of the 8 samples can be calculated. Relevant scale parameters and shape parameters of Weibull distributions also given by Minitab software.

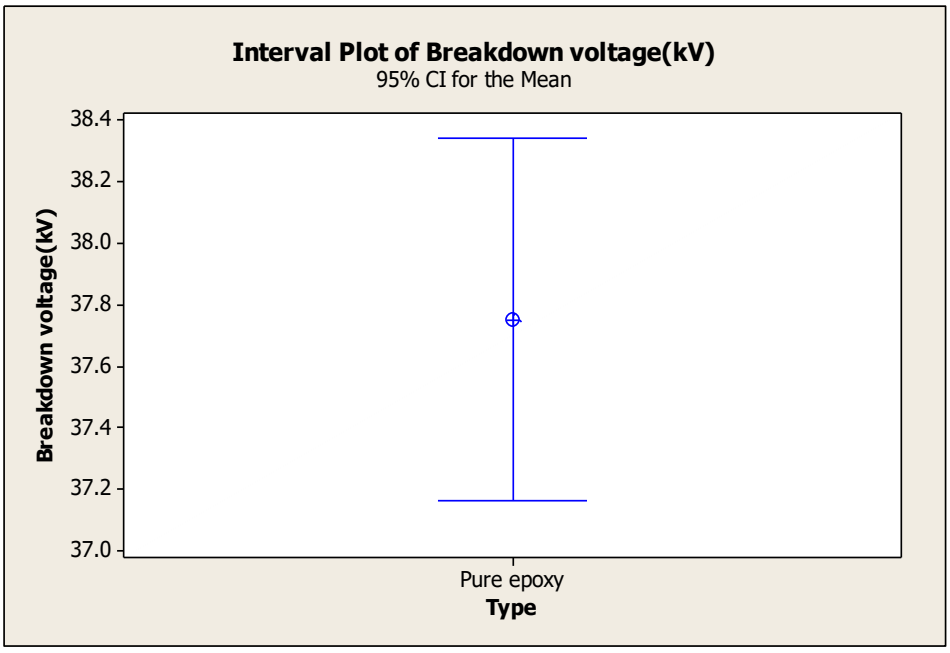



**Figure 6.1: Distribution Overview for Breakdown Voltages of pure epoxy**

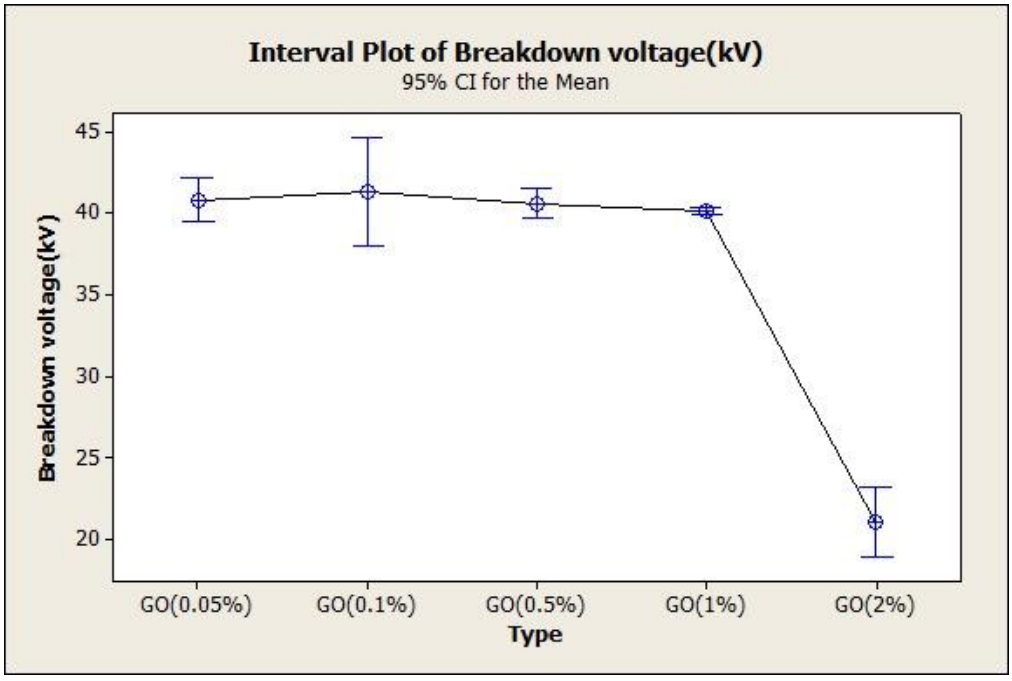



**Figure 6.2: Distribution Overview for Breakdown Voltages of Graphene oxide**

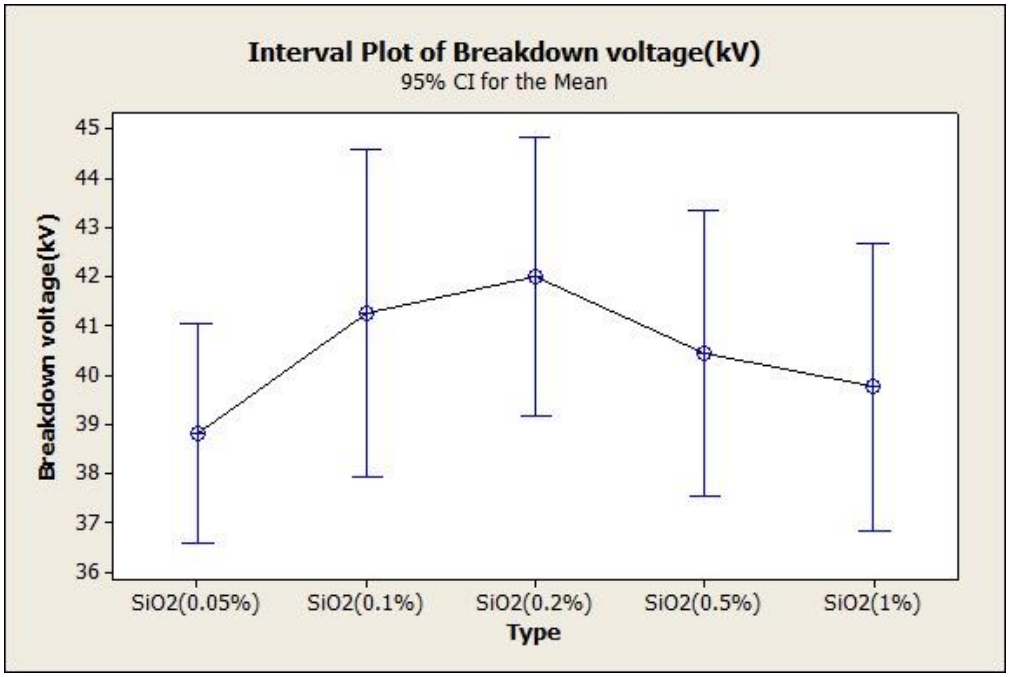



**Figure 6.3: Distribution Overview for Breakdown Voltages of Silicon dioxide**

| Compositions | Mean breakdown voltage (kV) |
|---|---|
| Pure epoxy | 37.75 |
| Graphene oxide(Nano) + Pure epoxy | |
| 0.05% | 40.75 |
| 0.1% | 41.25 |
| 0.2% | 40.50 |
| 0.5% | 40.12 |
| 1% | 21.06 |
| Silicon dioxide(Nano) + Pure epoxy | |
| 0.05% | 38.81 |
| 0.1% | 41.05 |
| 0.2% | 42.00 |
| 0.5% | 40.44 |
| 1% | 39.75 |
| Graphene oxide (Nano)+ Silicon dioxide (Nano) + Pure epoxy | |
| 0.2%,0.2% | |
| Graphene oxide(Nano)+ Silicon dioxide(Nano)+ Pure epoxy | |
| 0.2%,0.01% | |
| 0.5%,0.01% | |

**Table 5.2: Mean breakdown voltage of compositions**

## 6.2 Relative permittivity and tan delta result analysis

There are two aspects of measuring Relative permittivity and tan delta either using a 'LCR Meter' or high voltage schering bridge. Relative permittivity and tan delta values required for simulating the whole strain type epoxy insulator using 'ANSYS Maxwell'. For testing those parameters, it is required to take one sample of each composition and make small parallel plate capacitance. Then using 'LCR Meter' capacitance and tan delta values can be measured. Relative permittivity can be calculated according following equation.

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

| Compositions | Relative permittivity | Tan delta |
|---|---|---|
| Pure epoxy | 4.894 | 0.0065 |
| Graphene oxide(Nano) + Pure epoxy | | |
| 0.05% | 4.548 | 0.021 |
| 0.1% | 4.422 | 0.017 |
| 0.2% | 5.004 | 0.016 |
| 0.5% | 5.265 | 0.021 |
| 1% | 5.467 | 0.030 |
| Silicon dioxide(Nano) + Pure epoxy | | |
| 0.05% | 4.438 | 0.015 |
| 0.1% | 4.452 | 0.019 |
| 0.2% | 4.864 | 0.025 |
| 0.5% | 5.258 | 0.016 |
| 1% | 5.109 | 0.104 |
| Graphene oxide (Nano)+ Silicon dioxide (Nano) + Pure epoxy | | |
| 0.2%,0.2% | | |
| Graphene oxide(Nano)+ Silicon dioxide(Nano)+ Pure epoxy | | |
| 0.2%,0.01% | | |
| 0.5%,0.01% | | |

**Table 5.3: Relative permittivity and tan delta of each composition**

It is not enough improving dielectric strength because if relative permittivity less even high dielectric strength of the material it cause some issues. Because lesser relative permittivity means higher electric field occurs inside or outside of the insulators. Higher electric field can lead surface discharge, partial discharge and creeping discharge as well. Using those permittivity test results if construct the graph it will be as following.

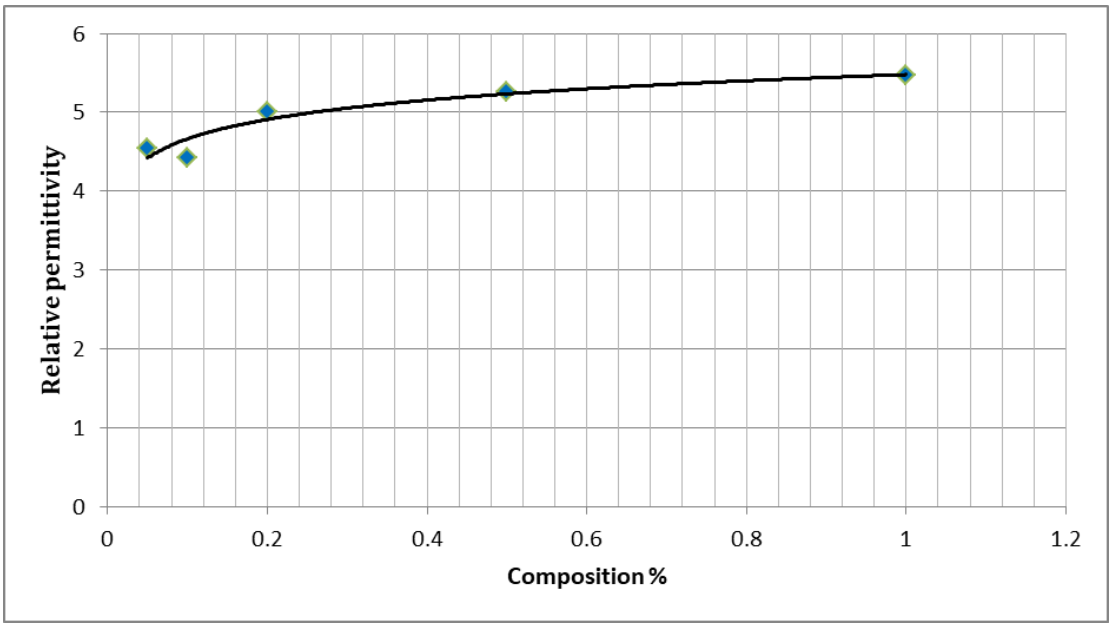



**Figure 6.4: Graph of Relative Permittivity of Silicon dioxide Compositions**

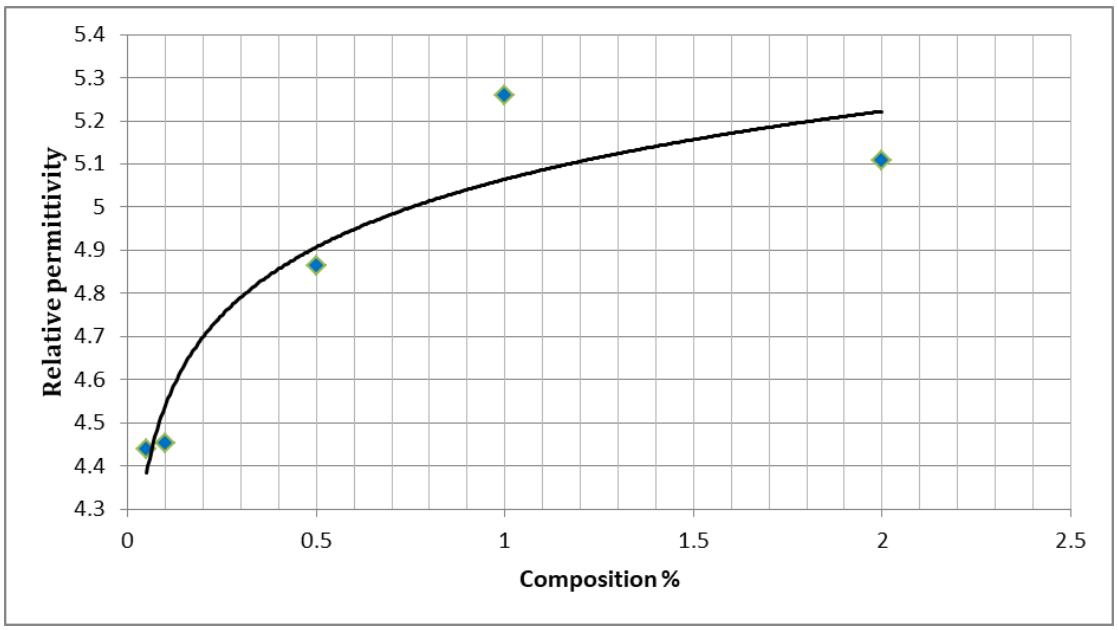



**Figure 6.5: Graph of Relative Permittivity of Silicon dioxide Compositions**

# Chapter 7

## 7. Simulations

Using Results mentioned in chapter 5 it can be simulated actual pin type insulator for checking whether it is suitable or not for practical applications. Simulation has done by using 'ANSYS Maxwell' software module. 3D pin type insulator drawing was drawn by using actual dimension of the insulator that was given by epoxy insulator manufacturer. Manufacturer name was 'AVS POLYMER LLP' and drawing was 33kV pin type epoxy insulator. Followings were the simulation steps.

### 7.1 Create the drawing in ANSYS Maxwell 3D environment

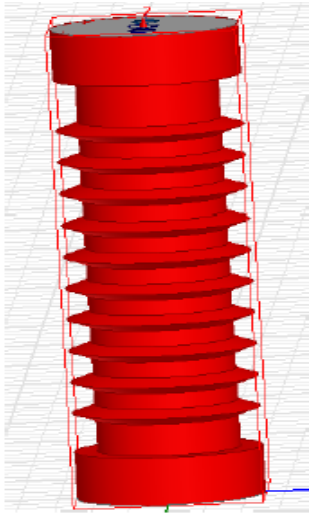


**Fig 7.1: Drawing of the Pin Type Insulator**

### 7.2 Adding each new material composition's properties to the software

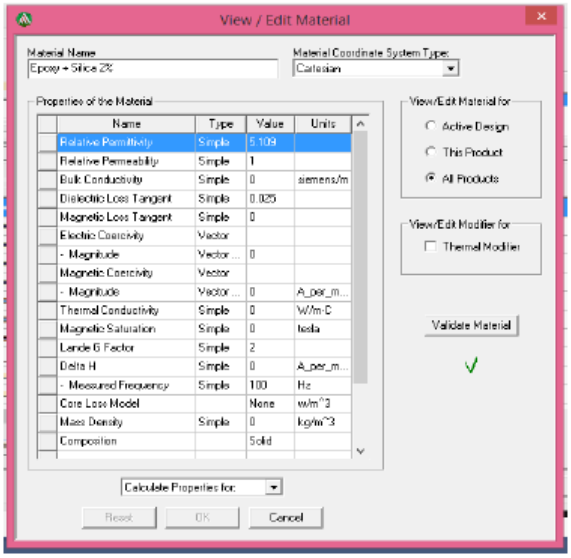



**Fig 7.2: Add New Material Properties to the ANSYS Maxwell**

## 7.3 Simulation for Distribution of Magnitude of Electric field

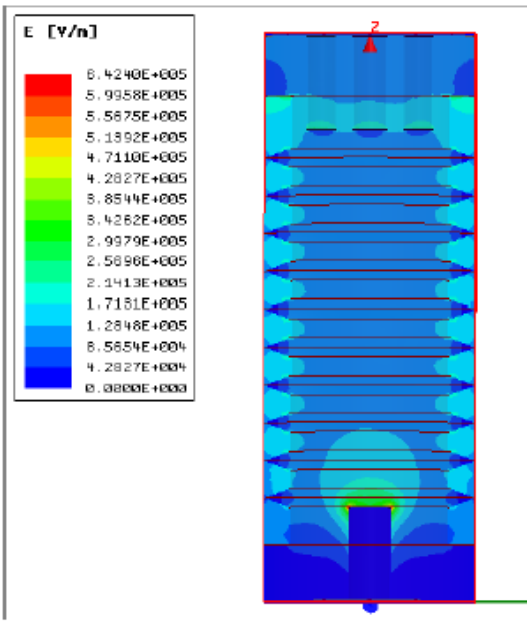



**Fig 7.3: Distribution of Magnitude of Electric field**

## 7.4 Simulation for Distribution of Electric field

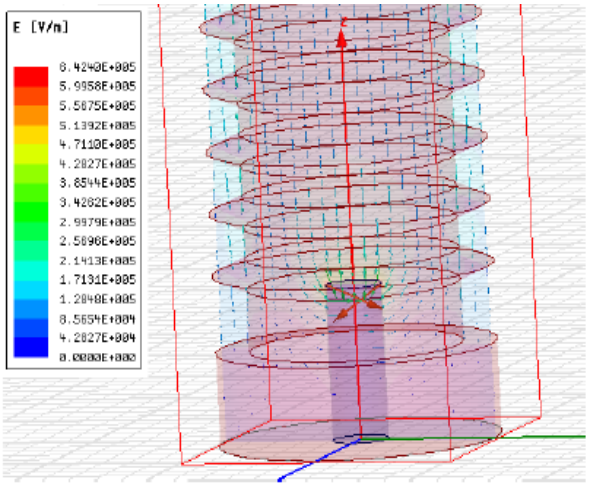



**Fig 7.4: Distribution of Electric field**

## 7.5 Simulation for Distribution of Voltage of the insulator's Surface

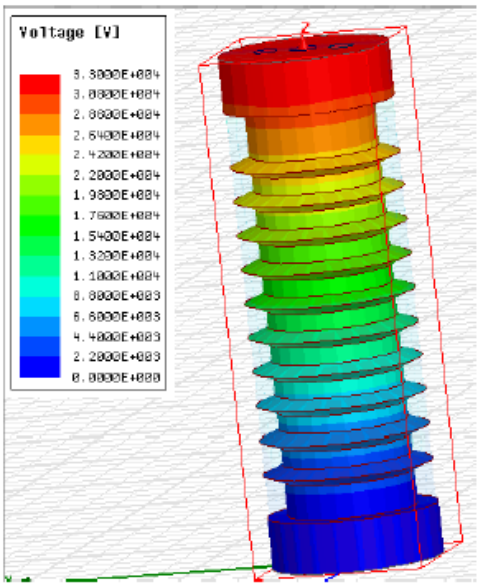



**Fig 7.5: Distribution of the Voltage of the Surface**

Looking at all above parameters and comparing each of material comparisons were done with pure epoxy. But in this simulation it can be seen that all the materials are acceptable when only comparing relative permittivity values for designing the insulator, ignoring the dielectric strengths. However it can be clearly seen that materials possess low concentrations of Nano fillers were tends to have lesser electric field. Lesser electric field means lesser of surface discharge, creeping discharge and etc. So likewise using simulations also we can optimize the material compositions. According to simulations fillers concentrations have 0.05% - 2% (w/w) have better resistance to the surface flashover.

# Chapter 8

## 8. Conclusions

Using above dielectric strengths and permittivity analysis of chapter 5 and ANSYS simulation done in chapter 6, it can be obtained some conclusions. Those conclusions that were found in this project would be as following,

- Nano composites with graphene oxide, silicon oxide and combination of these fillers were successfully fabricated.
- By adding silicon dioxide and graphene oxideNano particles to the epoxy resin the dielectric strength has been increased more than the pure epoxy sample. A maximum breakdown voltage can be seen for the composition of 0.2% (w/w) silicon dioxide particle sample. When concentration of the Nano particles are increased above 2% (w/w) the dielectric breakdown strength reduces drastically.
- The breakdown strengths of silicon dioxide and Graphene oxide look almost similar at lower concentrations but when concentration of the Nano particles are increased Graphene oxide shows much lower breakdown strength than silicon dioxide. Therefore both Nano particles can be used to improve the dielectric strength of epoxy composites.
- Relative permittivity is slightly high when having lower Nano filler concentration such as 0.5% - 2% (w/w) for all fillers that were used in this project.
- When fabricating the Nano composites it is found that using graphene oxide and silicon oxide together with epoxy resin there was a phase separation for compositions more than 0.1% (w/w) therefore it is inappropriate to use both graphene oxide and silicon oxide as fillers to the epoxy resin.

So overall when looking at the dielectric strength and relative permittivity it is recommended to use graphene oxide and silicon oxide 0.05% - 2% (w/w) filler concentration with epoxy.