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Electrical and Thermal Characterization of Organic Varnish Filled with ZrO_2 Nano Filler Used in Electrical Machines

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Abstract – In the last decade it has been witnessed significant developments in the area of nano particles and nano scale fillers on electrical, thermal, and mechanical properties of polymeric materials such as resins, varnishes, enamel and bakelites. The electric and thermal properties were more important in the electrical equipments for both steady state and transient state conditions. This paper deals with the characterization of the electric and thermal properties of the pure varnish and zirconia (ZrO_2) filler mixed varnish. The electric properties such as dielectric loss (tan δ), dielectric constant (ε), dielectric strength and partial discharge voltage were analyzed and detailed for different samples. It was observed that zirconia nano filler mixed varnish has the superior dielectric and thermal properties when compared to those of standard varnish. It has shown that at power frequency the 1wt% nano composite sample has the higher permittivity value when compared to other samples. It has been examined that the 1wt% sample was having higher inception and extinction voltages when compared to other samples. It has been observed that 1wt% sample has higher dielectric strength when compared with other samples. There has been an improvement of thermal property by adding few weight percent of zirconia nano fillers. There was not much variation in glass transition among the nano mixed composites. The weight loss was improved at 1wt% of the zirconia nano fillers.

Keywords: Zirconia, Nano fillers, Varnish, Dielectric strength, TGA

1. Introduction

In Different types of insulating medium such as gas, solid, vacuum, liquid and composite was used for electrical power apparatuses. The important parameters considered for selecting the dielectric materials were Dielectric strength, Conductivity, Dielectric constant, Loss factor, Flash point, Gas content, Viscosity, Mechanical strength, Compressive strength, Bonding strength, Surface resistance, Tracking resistance and Chemical properties. Organic varnishes and solvent less resin were widely used in the Insulation system of electrical machines for impregnation and finishing applications [1-3]. Impregnating and finishing agents offer several advantages, such as increased mechanical bonding to the winding wire, improved dielectric properties, improved thermal conductivity and protection to the winding against moisture and chemically corrosive environment. Elmo Luft 1A-FD was an anti tracking finishing varnishes having phenolic chemical base. It was an insulation of class B having the temperature limit of 130°C. It has the following distinctive characters such as fast air drying, anti-tracking and clear. It was used for Coating on PCB, SRBP components, impregnation of small coils and stators. The basic characteristic of dielectric materials were expressed in terms of mechanical, thermal, electrical, magnetic optical, chemical and physical properties. The behaviour of the dielectric materials under applied forces and loads were determined by means of mechanical properties. Some of the important mechanical properties were stiffness, ductility, hardness, toughness, creep and malleability. Thermal properties were used to determine the behaviour of the dielectric materials when they were subjected to variation in temperature. The most important thermal properties needed for the dielectric materials were specific heat, thermal expansion, thermal conductivity and thermal shock resistance [2]. These properties were needed to determine the thermal withstanding capacity and the life time of the apparatuses when they are subjected to the thermal changes. Heat was developed in the motor due to the loads and over voltages. Thermal withstanding capacity depends upon the amount of the heat produced by the windings of the motor under the loaded condition. The heat produced under the different conditions of the load can be found by heat run test whereas the heat produced by over voltages cannot be found. The heat produced by the motor at the different load conditions would be helpful for determining the life time of the motor. Heat produced by the over voltages would damage the windings of the motor and the amount of heat produced due to over voltages cannot be found by normal heat run test. The dielectric property depends upon the atomic structure of the material. For crystals, the dielectric

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constant depends on the direction along materials [3-5]. The passage of electrons through insulators by jumping from one energy level to another in the forbidden band due to the presence of impurities or structural defects was called as Hopping effect. It seems that from the electrodes, the electrons are believed to be ejected by either Schottky's emission effect or field emission effect [4]. Dielectric strength depends upon the environment, electrode type, electrode surface and the method of testing.

The failure of the insulation was due to breakdown of the varnish or the enamel, partial discharge, dielectric heating and space charge formation. The insulation of the motor should have high resistance to partial discharge, improved thermal properties [5]. The mechanism of failure and breakdown strength depends upon the time of voltage application. The important breakdown mechanisms in solids were as follows:

1. Intrinsic breakdown
2. Streamer breakdown
3. Electromechanical breakdown
4. Edge breakdown and treeing
5. Thermal breakdown
6. Erosion breakdown
7. Tracking

Organic insulation was mostly affected by tracking. The formation of permanent conducting path across the surface of insulation was called as tracking. The process of tracking was shown in the Fig. 1. Tracking limits the usage of organic insulation in outdoor environment [6-8]. The rate of tracking depends upon the structure of the polymers. However it can be drastically slowed down by adding appropriate fillers such as Al_2O_3, SiO_2, ZnO, ZrO_2, CNT, and TiO_2 to the polymers to avoid carbonization.

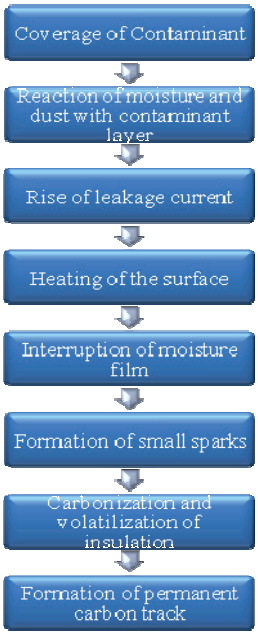


Fig. 1. Process of tracking

Nano fillers added to the varnish would have the following advantages:

1. High resistance to partial discharge
2. Improved thermal properties
3. Lacking of erosion resistance
4. Matching of coefficient of thermal expansion
5. Thermal conductivity enhancement
6. Mechanical reinforcement
7. Abrasion resistance
8. Improved life

In this research paper, some important properties of organic varnish filled with nano fillers of ziconia were discussed.

2. Synthesis and Characterization of Zirconia Nano Filler

2.1 Synthesis of zirconia nano filler

For Different methods were used for the nano particle preparation. Some of these methods were as follows: Chemical precipitation, Sol-gel technique, Polymeric precursor, Micro emulsion, Hydrothermal synthesis, Combustion synthesis, DC Arc Plasma Process, RF Plasma Process, Plasma Rapid Solidification Technology, Reactive Electrode Submerged Arc, Spray pyrolysis, Gas condensation, Freeze drying, Ultrasonic methods and ball mill method. Due to the ease availability of ball mills, the micro powders of zirconia were converted into nano particles by means of the ball mill method. The micro particles were crushed by the small balls present inside the ball mill for nearly 40 hours. Then the nano powders of ZrO_2 were obtained effectively. This method was also economic. So it was used for the nano particle preparation. Then the prepared nano particles of ZrO_2 were subjected to SEM analysis to augment and confirm the particle size of the prepared nano powders.

2.2 Characterization of zirconia nano filler

The zirconia particles were subjected to scanning electron microscopy studies to analyze the surface and structure of the particles. The principle of scanning electron microscopy and the obtained SEM pictures and their interpretations were explained clearly. The samples must be conducting (in order to accelerate electrons into the sample) and hence a biological sample must have a gold layer deposited on its surface if it is to be investigated by SEM or STEM. In the STEM, the sample is a very thin specimen and contrast within the image is due to the spatial variations in intensity of the transmitted electron beam through the specimen, as the beam is raster scanned over

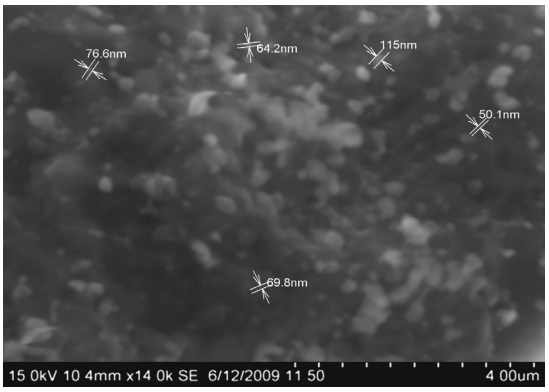


Fig. 2. SEM analysis of zirconia at 4µm

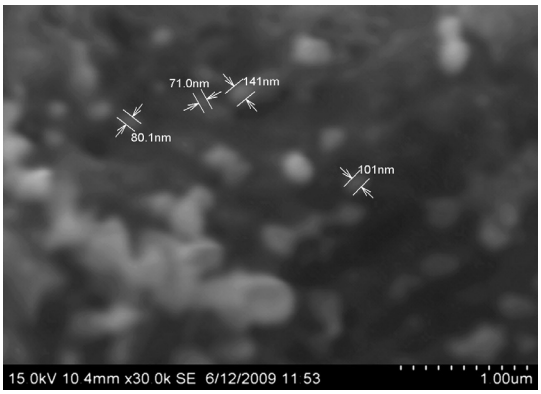


Fig. 3. SEM analysis of Zirconia at 1µm

the specimen. In SEM, the image may be produced in a number of ways from variations in the intensity of secondary electrons back-scattered from the specimen through to X-ray emission produced by inelastic collisions of the primary beam with bound electrons in the specimen [8-10]. From the analyzed SEM image the particles were in the form of nano metric range varies for one area to other. The sizes of the particles were in the range from 50 to 120 nm size. The SEM analysis of zirconia was shown in Figs. 2 and 3.

3. Sample Preparations

The organic varnish used in the motors was in the fluid nature having high viscosity. So it was difficult to study the electrical and thermal properties of it. In order to characterize the electrical and thermal properties of the varnish filled with zirconia nano fillers, the fluid varnish was converted into solid. The process of conversion of varnish from its fluid state to solid was done as per the chemical standards without affecting the internal properties of the varnish.

3.1 Selection of the sample

The pH value of the varnish was found by pH meter. The region in which the sample was lying i.e. acid, base or neutral region was found. The sample was acidic when the pH value was less than 7. It was base when the pH value was greater than 7. When the pH value was equal to 7, it was neutral. The pH value of the varnish was found to be 4. So it was acidic in nature. When the varnish was acid, the base type nano material was added. If the varnish was base, acidic nano material was added. The process of converting liquid state organic varnish into solid state sample was called as curing. The curing methods were of two types.

(1) Thermal curing: The oligomer which was having a repeat unit (1 to 10) was converted into polymer by using thermal curing.
(2) Radical initiator curing: In this method, curing agents such as amines, anhydrates and acids were used as curing agents.

3.2 Preparation of the sample

The nano composite samples were prepared by radical initiator curing method. 80% of organic varnish having phenolic base and 20% of epoxy resins were taken. DDM (Diamino Diphenyl Methane) was taken as the curing agent. 0.27g of DDM was taken for 1g of resin. The DDM was melted for 10 minutes at 60-80°C using magnetic mantle. Then the varnish, resin and melted DDM were taken in a beaker. The die should be coated by anabond 666 before pouring the mixture. Then it was placed in an oven at a temperature of 80°C for 1 hour. After the mixture was poured in to the die which was coated by a Teflon sheet, it was heated at 80° C for 2 hours for epoxy curing and 120° C for 3 hours. After this time period it was cooled for 1 hour to obtain a solid nano composite sample. Four series of specimens were produced, each one with different filler content, starting from 0 wt% (pure varnish), 1, 3 and 5wt% weight. Then these samples were subjected to different studies to characterize the electrical and thermal properties of the standard varnish and varnish filled with ZrO_2 nano fillers.

4. Measurements of Electrical Properties

4.1 Dielectric spectroscopic result analysis

Dielectric spectroscopy also known as Electrochemical Impedance Spectroscopy was used to measure the dielectric properties of a medium as a function of frequency. It was based on the interaction of an external field with the electric dipole moment of the sample, often expressed by permittivity. Here the dielectric measurements were carried out by Impedance spectroscopy (LCR HITESTER 3532-50) measuring instrument. It was also an experimental method of characterizing electrochemical systems [9-12]. This technique was also used to measure the impedance of a system over a range of frequencies, and the frequency

response of the system including the energy storage and dissipation properties. The prepared nano composite sample was sliced to an area of 0.5 x 0.5 cm^2 then it was placed between the electrodes of dielectric spectroscopy at various temperatures for the frequency range of 0 - 5 MHz. Dielectric Spectroscopy was used to obtain the various electrical parameters like impedance, admittance, impedance phase angle, static capacitance in series, static capacitance in parallel, loss coefficient, inductance in series, inductance in parallel, Q factor, effective resistance in series, effective resistance in parallel, conductance, reactance, susceptance with respect to constant temperature and variable frequency. Real and imaginary parts of relative permittivity of the samples were calculated by the following equation which was also used to calculate the dielectric loss.

Loss factor $$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \quad (1)$$

Where the Real Part of Relative permittivity

$$\varepsilon_r' = \left(\frac{t * C_p}{A * \varepsilon_0}\right) \quad (2)$$

Imaginary part of relative permittivity

$$\varepsilon_r'' = \left(\frac{t}{\omega * R_p\, A * \varepsilon_0}\right) \quad (3)$$

From the dielectric spectroscopy analysis the various parameters have been analyzed for pure organic varnish having phenolic base (0 wt%) and zirconia mixed varnish for various weight percentages were 1, 3 and 5wt%. The permittivity was determined by the parallel capacitance whose values were obtained from dielectric spectroscopy instrument. The formula used for the calculation of permittivity was

$$\varepsilon_r = \frac{C_p * d}{\varepsilon_0 * A} \quad (4)$$

Where C_p was parallel capacitance, d was thickness of the sample and A was area of the sample.

The permittivities versus frequencies at various temperatures with different samples are shown graphically in the Fig. 4. Good insulating materials have higher permittivity values. From these results when the temperature was higher the dielectric constant (permittivity) was also higher. At 300°C the permittivity was higher when compared to 60°C and 155°C temperatures. As the frequency increases the permittivity also comes down. At lower frequencies the permittivity was higher because the settling time was higher in polarization. Hence the permittivity was higher.

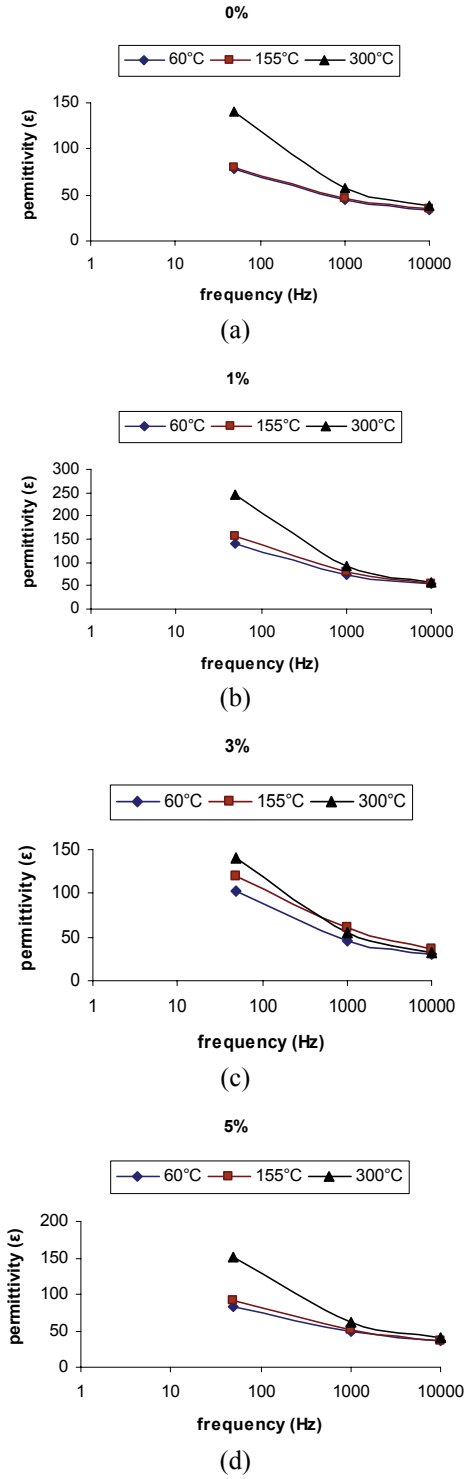


Fig. 4. Permittivity versus frequency at various temperatures for (a) 0%; (b) 1%; (c) 3%; (d) 5%

At higher frequencies settling time was lower and the polarization fails to settle itself, so the permittivity was having a lower value. At 10 kHz above frequency range there was a small variation in permittivity. Among these graphs the 1% graph has higher permittivity value. A good insulating material should have a lower dielectric loss. Dielectric loss was the loss of power in a dielectric caused

by the loss of energy in the form of heat generated by an electric field. The dielectric loss was given by

$$\tan \delta = \sigma / \omega \varepsilon . \quad (5)$$

Fig. 5 represents the dielectric loss versus various frequencies at various temperatures. From these results, it was shown that when the frequency increases, the dielectric loss decreases. At lower frequencies, dipoles were able to keep in phase with changes in electric field and power losses were low. When the frequency was increased to the point at which dipole orientation cannot be completed in time available and the dipole becomes out of phase. This internal friction leads to generation of heat. When the frequency was increased further there was no time for substantial dipole movement so the power losses were reduced. The dielectric loss becomes higher at 300°C for power frequency. At lower temperature in power frequency the dielectric loss was not much variable for the nano composites. The dielectric losses become higher at 1% sample from 50Hz to 1 kHz. For an insulating materials used in high voltage engineering, the quality

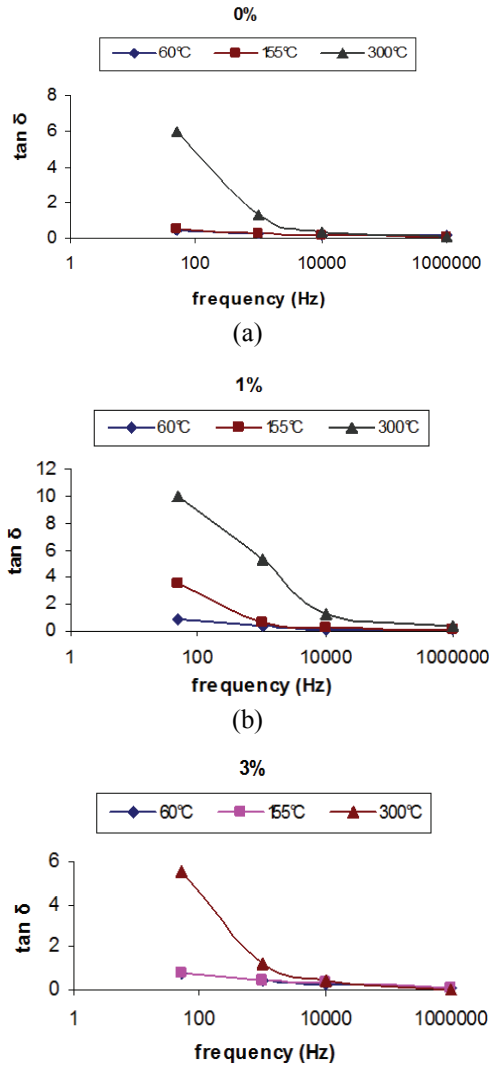


Fig. 5. Dielectric losses versus frequency at various temperatures for (a) 0% (b) 1% (c) 3% (d) 5%

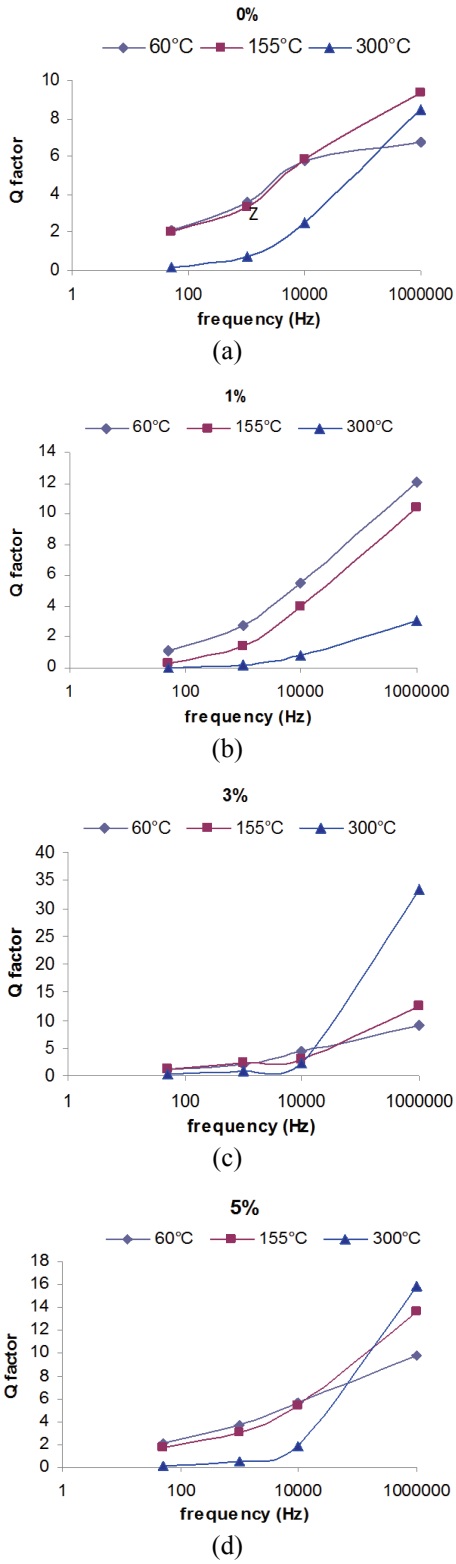


Fig. 6. Q factor versus frequency at various temperatures for (a) 0% (b) 1% (c) 3% (d) 5%

factor of the material was important. For the good insulating materials the quality factor should be higher. Generally quality factor was defined in terms of the ratio of the energy stored in the resonator to that of the energy being lost in one cycle. The quality factor was inversely proportional to the dielectric loss (tanδ). It was given as

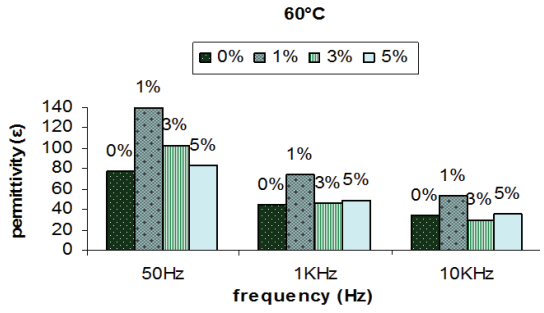
$$(\text{Q factor}) = 1/\tan\delta \tag{6}$$

The quality factor versus frequency at various samples with different temperatures was shown in Fig. 6. As the frequency was increased the quality factor was also increased. At higher temperature and at power frequency the quality factor was low but at the frequency of 1MHz the quality factor varies with the variation in temperatures. As the temperature was increased the quality factor comes down because of the dielectric losses due to conduction current.

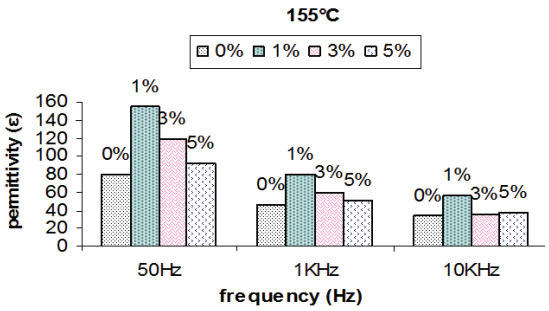
4.2. Comparison of dielectric loss and Q factor for pure and Zro_2 nano filler mixed organic varnish

The comparison of permittivity versus frequencies for various samples at 60°C and 155°C were exposed graphically in Fig. 7.

The permittivity value was higher at 1wt% for all the frequencies at a temperature of 60°C when compared to other sample. It has also shown that at power frequency the 1wt% nano composite sample has the higher permittivity value when compared to other samples. As the frequency



(a)



(b)

Fig. 7. Permittivity versus frequency for various samples at (a) 60°C (b) 155°C

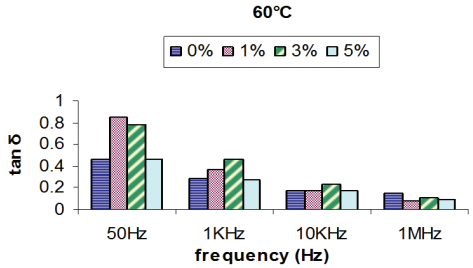


Fig. 8. Dielectric losses versus frequency at various samples

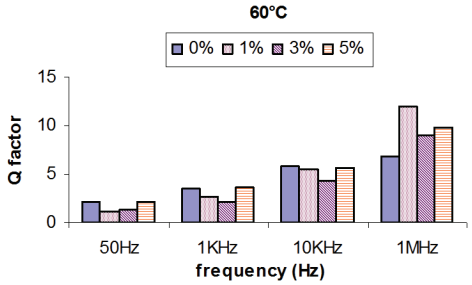


Fig. 9. Q factor versus frequency at various samples

was increased the permittivity was also decreasing to least values.

The dielectric loss (tanδ) versus frequency for various samples at 60°C was shown in Fig. 8. When the frequency was increased the dielectric loss was also decreased. It was found that the 1% sample has higher dielectric losses at power frequencies and lower dielectric loss at higher frequencies.

The quality factor was defined as the quality of the materials. It was inversely proportional to the dielectric loss. As the frequency was increased the quality factor was also increased. The Fig. 9 shows quality factor versus frequency at 60°C. At 1MHz 1wt% sample was having improved quality factor.

4.3 Partial discharge measurement

A partial discharge (PD) was a localized dielectric breakdown of a small portion of a solid or liquid electrical insulation system under high voltage stress. PD was usually beginning within voids, cracks, or inclusions within a solid dielectric, at conductor-dielectric interfaces within solid or liquid dielectrics, or in bubbles within liquid dielectrics. For solid insulating materials, certain criteria were available for the measurement of the breakdown voltage or the breakdown field strength on plate-like samples in a homogeneous or weakly inhomogeneous field [10-12]. A standardized testing arrangement for the determination of the breakdown field strength of plates or foils up to sample thickness of 3mm as per IEC 60243-1 was as shown in Figs. 10 and 11. The arrangement of electrode setup for PD and BD measurements was revealed in Fig. 10. The size of the electrode configuration was given below.

- Sample thickness : 3 mm
- Diameter of upper electrode : 25mm
- Diameter of lower electrode : 75mm
- The entire arrangement in an insulating liquid with a higher dielectric constant (Ex: Insulating oil).

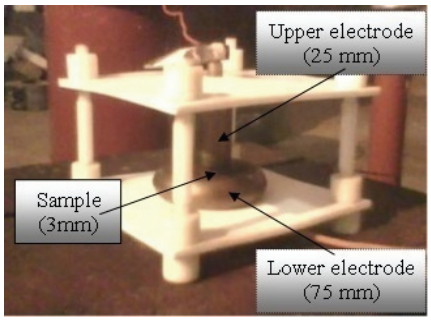


Fig. 10. Electrode setup for PD and BD measurements

The experimental set up used for partial discharge measurement is shown in Fig. 11 and allowable pC level for different conditions is shown in Table 1.

4.4 Tables

The partial discharge inception voltage and partial discharge extinction voltage for different electrode configurations with oil were summarized. The different values of PD inception and extinction voltages and capacitance value for uniform field and non uniform field configurations were shown in Tables 2 and 3. It has been examined that the 1wt% sample was having higher

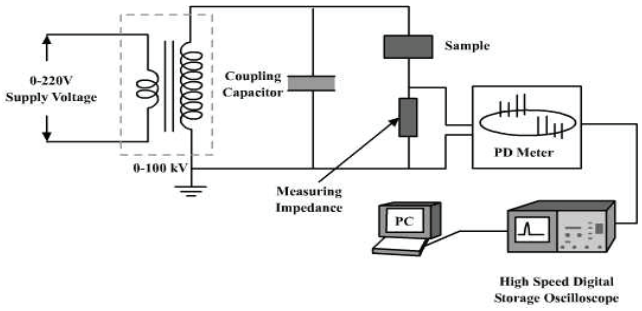


Fig. 11. Experimental setup for PD measurement

Table 1. Allowable pC level for different conditions

Type of condition	Allowable level
Shielded	Less than 2 pC
Unshielded	7 pC

Table 2. Inception and extinction voltages

Sample	Inception voltage (kV)	pC	Extinction voltage (kV)	pC
0wt%	4.8	39	4.1	1.5
1wt%	5.5	40	4.5	1.2
3wt%	5.0	35	4.1	1.3
5wt%	5.1	33	4.2	1.1

Table 3. Increase in Inception and extinction voltages

Sample	% Increase in Inception voltage	% Increase in Extinction voltage
0 %	-	-
1 %	14.58	9.75
3 %	4.16	-
5 %	6.25	2.43

inception and extinction voltages when compared to other samples.

4.5 Dielectric strength measurement

The dielectric strength of an insulating material could be defined as the maximum dielectric stress which the material can withstand. It could also be defined as the voltage at which the current starts increasing to a very high value unless controlled by the external impedance of the circuit. The electric breakdown strength of insulating material was dependent on a variety of parameters, such as pressure, temperature, humidity, field configurations, nature of applied voltage, imperfections in dielectric materials, material of electrodes, and surface conditions of electrodes, layer thickness, and type of voltage, stress duration and frequency [12-13]. It was known that the breakdown voltage was also dependent on the nature and smoothness of the electrode material. The breakdown strength was reduced considerably due to the presence of impurities. The breakdown field strength was an extraordinary important material property for dimensioning an insulation system. The most common cause of insulation failure was the presence of discharges either within the voids in the insulation or over the surface of the insulation. In order to prevent gliding discharges along the surface of the insulating plate, the entire arrangement was embedded in an insulating liquid with higher dielectric constant. The breakdown test was conducted with alternating voltage, which should be increased from zero to the breakdown value within 10-20 s as per the circuit diagram shown in the Fig. 12. The median value of the breakdown voltage was determined from five samples.

The values of breakdown strength at various samples for uniform field configuration thickness of 3mm as per standard IEC 60243-1 were shown in Table 4. It has been observed that 1wt% sample has higher dielectric strength

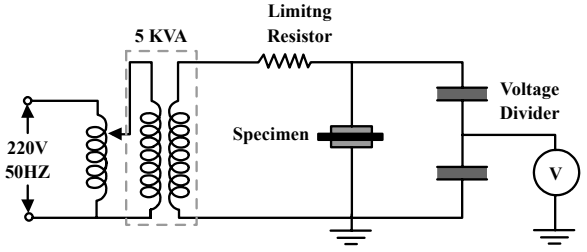


Fig. 12. Experimental setup for the measurement of dielectric strength

Table 4 Dielectric strength of pure, 1, 3 and 5wt% samples

Sample	Dielectric Strength (kV/cm)	% Increase
0wt%	2.56	-
1wt%	3.58	39.84
3wt%	3.08	20.31
5wt%	2.98	16.40

when compared with other samples.

5 Analysis of Thermal Properties

In equipment and installations for the supply of electricity, heat was generated by ohmic losses in conductors, through dielectric losses in insulating materials and through magnetization and eddy-current losses in the iron. The insulating materials should have only a very low thermal stability. The permissible temperature rise of the insulating material often restricts the use of the equipment. Knowledge of the thermal properties of the insulating materials was, therefore, important for the construction and design of equipment and setups. The most important thermal properties of the insulating materials were specific heat, Heat transport, linear thermal expansion, and thermal stability [1] [11-12]. A generally accepted definition of thermal analysis was given as follows: "A group of techniques in which a physical property of a substance and/or its reaction products was measured as a function of temperature whilst the substance was subjected to controlled temperature program". It was based upon the detection of changes in the heat content (enthalpy) or the specific heat of a sample with temperature. As thermal energy was supplied to the sample its enthalpy increases and its temperature rises by an amount determined, for a given energy input, by the specific heat of the sample. The specific heat of a material changes slowly with temperature in a particular physical state, but alters discontinuously at a change of state. As well as increasing the sample temperature, the supply of thermal energy may induce physical or chemical processes in the sample. Such enthalpy changes may be detected by thermal analysis and related to the processes occurring in the sample. Thermal analysis can be done by different methods such as the measurement of heating curves, dynamic adiabatic calorimetric, differential thermal analysis (DTA), differential scanning calorimetric (DSC), thermo gravimetric (TG), thermal mechanical analysis (TMA), dynamic mechanical thermal analysis (DMTA).

5.1 Differential Scanning Calorimetric Analysis (DSC)

The objective of DSC was to measure the amount of energy (heat) absorbed or released by a sample as it was heated, cooled or held at a constant (isothermal) temperature. When an exothermic or endothermic change occurs in the sample material, energy was applied or removed to one or both furnaces to compensate for the energy change occurring in the sample. Since the system was always directly measuring energy flow to or from the samples, DSC can directly measure melting temperature, glass transition temperature, temperature onset of crystallization, and temperature onset of curing [13]. The kinetic software enables to analyze a DSC peak to obtain specific kinetic parameters that characterize a reaction process. Fig. 13 shows DSC curves for different transitions and reactions of a polymer.

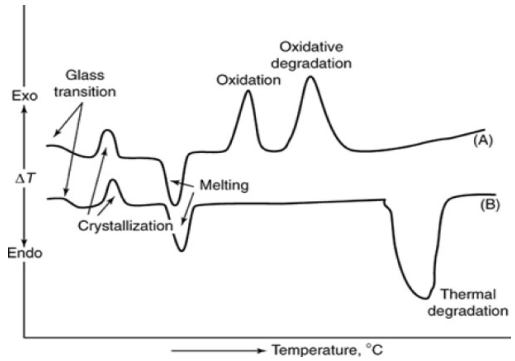


Fig. 13. DSC curves showing different transitions and reactions of a polymer

5.2 Thermo Gravimetric Analysis (TGA)

Thermo Gravimetric Analysis (TGA) was a simple analytical technique that measures the weight loss (or weight gain) of a material as a function of temperature. As materials were heated, they can lose weight from a simple process such as drying, or from chemical reactions that liberate gases. Some materials can gain weight by reacting with the atmosphere in the testing environment. Since weight loss and gain were disruptive processes to the sample material or batch, knowledge of the magnitude and temperature range of those reactions are necessary in order to design adequate thermal ramps and holds during those critical reaction periods [12-13]. In the Diamond TG/DTA 6000 Instrument system the sampling size could be analyzed from 0.1mg to 10g and the heating rate of 0.1-50°C/min for the temperature range from 50°C to 700°C [13]. This instrument was used to measure the sampling purity, reaction rate, identification, activation energy and heat of reactions. The TGA result of the pure organic varnish was shown in the Fig. 14 and the glass transition temperature was 200°C and the melting temperature was 551.98°C.

There was the significant improvement in the thermal properties by adding zirconia nano filler into the pure organic varnish. The TGA result for 1wt% of zirconia mixed organic varnish was shown in the Fig. 15. It has been noted that for 1wt% of zirconia mixed varnish, the glass transition occurred at the temperature of 210°C and the melting occurred at temperature of 565°C.

Similarly it has been obtained that for 3wt% of zirconia mixed organic varnish, the glass transition occurred at the

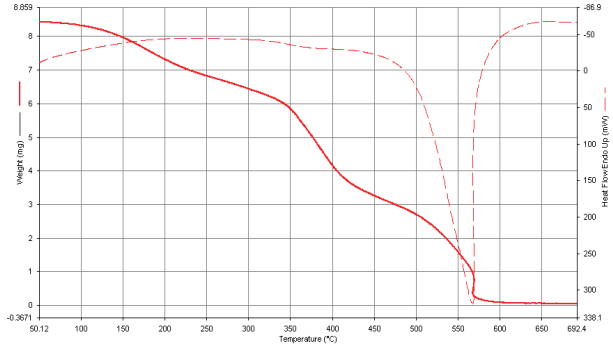


Fig. 14. TGA result for pure organic varnish

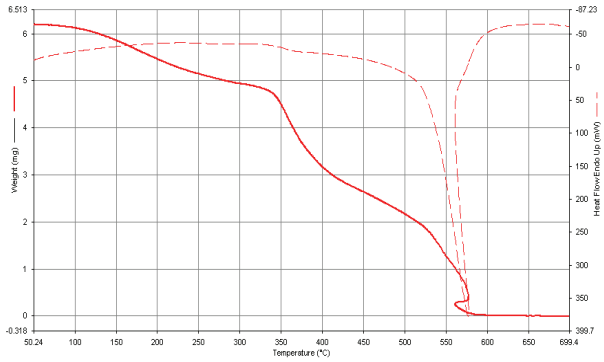


Fig. 15. TGA result for 1 wt% zirconia mixed organic varnish

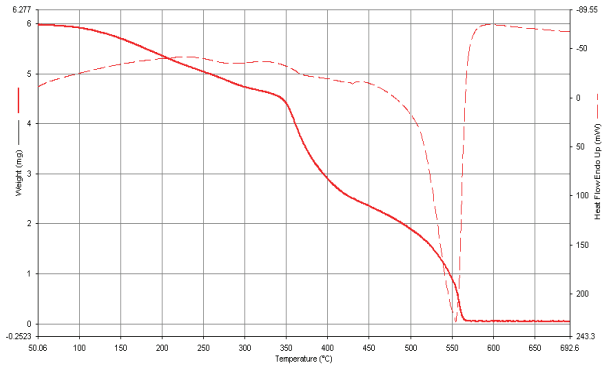


Fig. 16. TGA result for 3 wt% zirconia mixed organic varnish

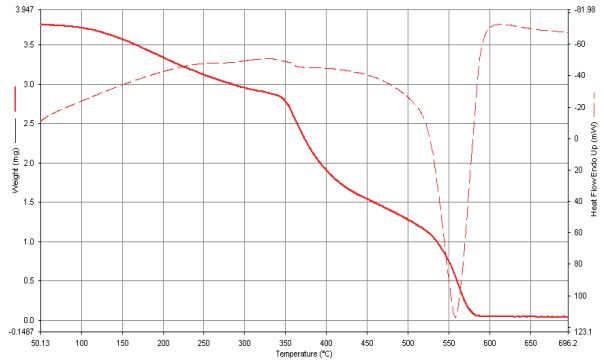


Fig. 17. TGA result for 5wt% zirconia mixed organic varnish

Table 5. Glass transition temperature of pure, 1, 3 and 5wt% samples

Sample	Glass Transition Temp (°C)	% Increase
Pure	200	-
Nano composites	205-210	2.5 - 5

Table 6. Melting point temperature of pure, 1, 3 and 5wt% samples

Sample	Melting Point Temp (°C)	% Increase
0wt%	551.98	-
1wt%	565	2.35
3wt%	556	0.72
5wt%	560	1.45

temperature at 210°C and the melting occurred at the temperature at 556°C. Fig. 16 shows TGA result for 3 wt% zirconia mixed organic varnish.

Fig. 17 shows TGA result for 5wt% zirconia mixed organic varnish. It has been obtained that for 5wt% of zirconia mixed organic varnish, the glass transition occurred at the temperature at 208°C and the melting occurred at the temperature at 560°C.

The TGA result showing the glass transition and melting point temperature for various samples were listed in the Tables 5 and 6.

5.3.Comparison of weight loss for pure and Zro_2 nano filler mixed organic varnish

The test results were a graph of the TGA signal (actual weight loss or gain converted to percent weight loss) on the Y-axis plotted versus the sample temperature in °C on the X-axis. There were no major variation TGA results between pure, 3 and 5wt% samples, but TGA result with little variation in 1wt% nano composite samples. Fig. 18 shows the comparison of TGA results for various samples.

There was an improvement of thermal property by adding few weight percent of zirconia nano fillers. There was not much variation in glass transition among the nano mixed composites. The weight loss was improved at 1wt% of the zirconia nano fillers.

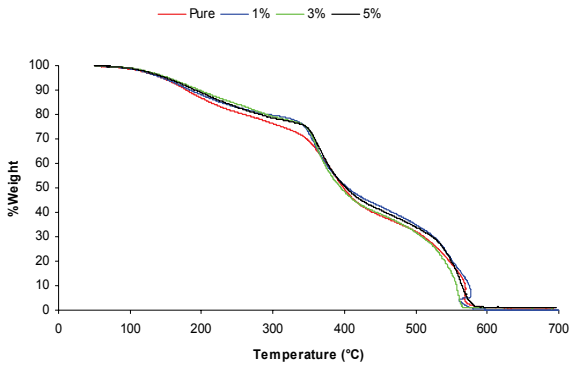


Fig. 18. Comparison of weight loss for various samples

5.4 Importance of thermal property for the dielectric materials

The dielectric property of pure and nano composite sample were described as a function of temperature. The permittivity and dielectric loss were observed as a function of temperature. It has been shown that the permittivity of the dielectric material was as the function of temperature. When the temperature was changed, the values of dielectric properties were also changed.

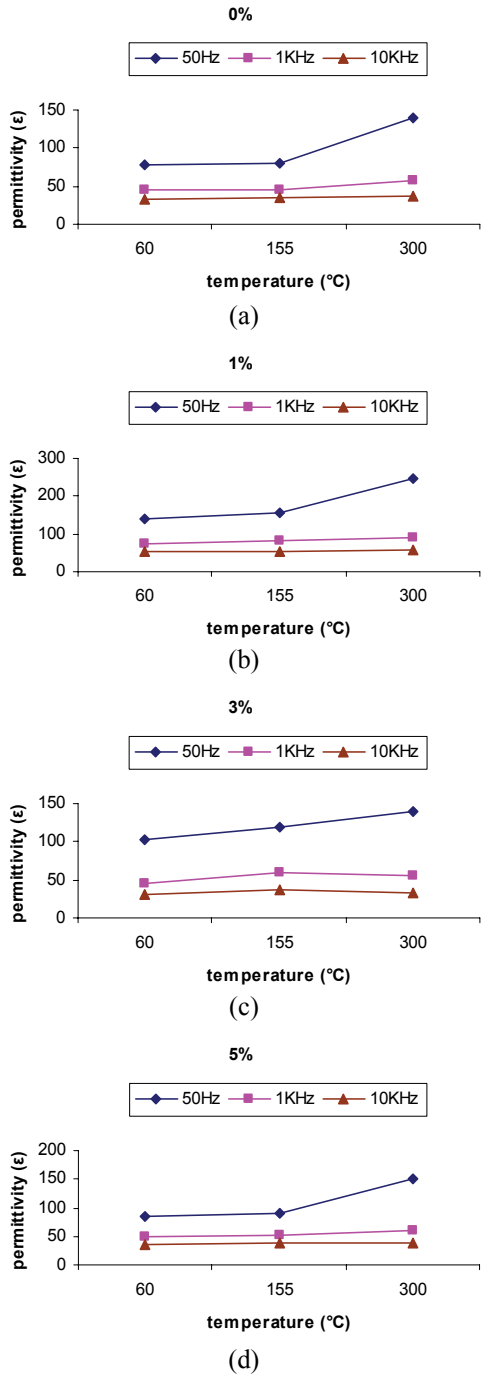


Fig. 19. Permittivity versus temperature at various frequencies for (a) 0% (b) 1% (c) 3% (d) 5%

Fig. 19 describes the permittivity versus temperature at various frequencies for different samples. The value of permittivity was higher at 300°C when compared to other temperatures for 50 Hz. As the temperature was increased the permittivity was also increased at 50Hz but there was not much variation at higher frequencies.

Fig. 20 illustrates graphically the dielectric loss versus temperature at various frequencies for different samples. From the results it has been found that as the temperature increases the dielectric losses also increases because of the conduction current in the dielectric materials. At 60°C and 155°C, the dielectric loss does not vary for all the samples. But at 300°C the dielectric loss was higher due to the

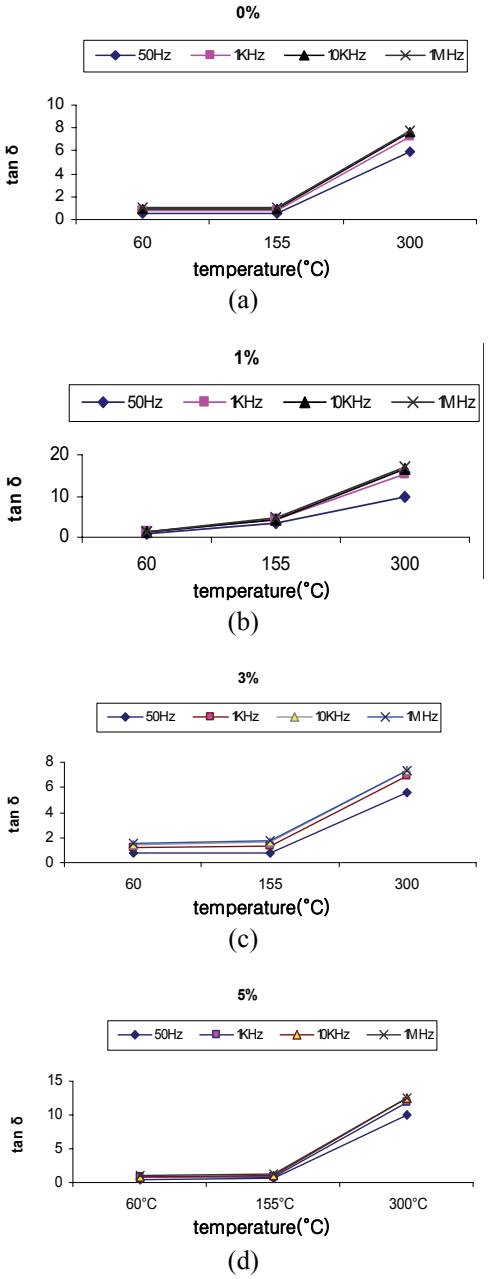


Fig. 20. Dielectric losses versus temperature at various frequencies for (a) 0% (b) 1% (c) 3% (d) 5%

electronic polarization effect.

6. Conclusions

It has been examined that the 1wt% sample was having higher inception and extinction voltages when compared to other samples. It has also shown that at power frequency the 1wt% nano composite sample has the higher permittivity value when compared to other samples. It has been observed that 1wt% sample has higher dielectric strength when compared with other samples. There was also an improvement of thermal property by adding few weight percent of zirconia nano fillers. There was not much variation in glass transition among the nano mixed composites. The weight loss was improved at 1wt% of the zirconia nano fillers.

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