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Temperature Dependence DC Conductivity in Nanostructured Alumina Filler Incorporated Polycarbonate Matrix

Sudha L. K.[1], Sukumar Roy[2], K. Uma Rao[3]

[1]Bangalore Institute of Technology, Bangalore, India.

[2]CTI, Corporate Research & Development, BHEL, Bangalore, India.

[3]Department of Electrical and Electronics Engineering, R.V.College of Engineering, Bangalore, India

Abstract: ***The paper describes temperature dependence of DC conductivity of polycarbonate matrix materials in which nano-structured amorphous alumina has been incorporated as a filler in certain commercial grades of polycarbonate polymers. The two commercial-grade polycarbonate materials, i.e., (PC-1, PC-2 grades respectively) are processed with different levels of nanostructured alumina filler material in the concentration range of 1 - 5 w% with the influence of heat and mechanical torque for mixing, in which homogenization between the filler material and polycarbonate takes place that results in nano-filler incorporated polycarbonate matrix materials. The DC conductivity of the derived polycarbonate matrix materials has been measured as a function of temperature under the supply of constant voltage from ambient temperature until just below the softening point (Tg) of both base and the composite materials. The results show that there is a decrease in the DC conductivity levels and hence an increase in the insulation resistivity (IR) as compared to that of the base polymer at any temperature, which is further found to be dependent on the level of incorporation of filler material in the polycarbonate matrix.***

Keywords: DC Conductivity, Insulation Resistance, Insulation Resistivity, Nano alumina , Polycarbonate .

1. Introduction

Polymers, which are reinforced with nanostructured materials dispersed at nano level, are known as polymer nano-composites. They are a new class of materials with an ultrafine dispersion of Nanomaterials [1] in a polymeric matrix. They exhibit more superior properties in terms of increased strength, improved heat resistance, decreased activation energy, increased capacitance, improved thermal behaviour at very low loadings of <5wt% of nano-fillers [2-5] as compared to the pure polymers.

Insulation resistance (IR) test is an insulation test which uses an applied dc voltage to measure insulation resistance in the range of M-ohms or Giga-ohms. The resistance indicates the condition of the dielectric between two conducting plates, where higher the resistance, better the insulation condition [6,7]. In ideal conditions, the insulation resistance would be infinite, but as no insulator [6-8] is perfect, the resistance value measured will be finite due to the leakage currents through the dielectric.

As per IEC standards IEC 60364-6(1), the IR values should be ≥0.5Mohms for low voltage applications. The insulation resistance is inversely proportional to the temperature [9, 10]. As temperature increases, the resistance would decrease and vice versa.

Among all the other physical properties, the electrical resistivity (ρ) and electrical conductivity (σ) characteristics of the solid phase play a prominent role in controlling the performance and stability of materials. The other physical properties include, density, melting point, entropy and crystal structure parameters etc. The electrical properties (resistivity and conductivity) of pure materials change with the temperature. The electrical properties [11,12] of polymers change with the incorporation level of nano fillers as well as the temperature.

Being a good electrical insulator, polycarbonates (PC) represent an industrially important polymeric material, extensively used in electronic PCBs. Because of its excellent durability, high impact resistance and flame retardant properties it is usable over a greater temperature range. It can also serve as a dielectric in high-stability capacitors. Because of the above characteristics [13,14] polycarbonate materials were used in this study solely to enhance the electrical insulation properties through nano-filler incorporation. Two specific grades of the said polymer were sourced commercially and taken as a base polymer material in this study.

Under the present background, the objective of this study is to measure DC conductivity as a function of temperature of certain polycarbonate polymers after modifying such polymers by incorporating nanostructured amorphous alumina material as filler. The polycarbonate composites have been prepared by incorporating the said filler material, (which is also a well characterised filler material, i.e., nanostructured amorphous alumina in various weight percentage) in the polymer matrix in the range of 1 – 5 w%. The filler material has been prepared at BHEL/CTI by following a patented process [3,4]. DC conductivity testing of the base polycarbonate and the composites was carried out at Indian Institute of Science, Bangalore. A decreased level of DC conductivity or enhanced electrical insulation characteristics [15,16] at any temperature was observed in the composite material as compared to the base polycarbonate material.

2. Experimental set up

A. Materials and the Di-electric Filler

The two polycarbonate materials (grades PC1100 and PC1220 respectively) [1,2] were sourced commercially (M/s Samsung Infino, India) in the form of solid beads and used as-received. The nano-dielectric filler material which is nanostructured amorphous alumina powder was synthesized at CTI/BHEL, Bangalore by a LPG-fired spray pyrolysis [3-5] system using an in-house patented process. The said alumina dielectric material has a primary particle size about 60 nm in the bulk agglomerated particles of the material that would be in a few to several microns. As mentioned, the level of incorporation of the said alumina material in both the polycarbonate grade materials was varied in the range of 1-5w% [6].

B. Sample Preparation and Processing

The composites were synthesized by mixing the solid crystals of polycarbonate materials (PC1 and PC2 grades) and the dielectric material (nanostructured alumina) in desired proportion using Haake Rheo Mixture at CIPET, Chennai, India as described in [7,8]. As per the requirement of DC conductivity measurement [9,10] as a function of temperature, the composites specimens were prepared with desired dimension by punching into square shapes (1cm x 1cm with thickness about 2 cm) using the bulk composite materials and also by maintaining uniform thickness in the sample.

C. Experimental Setup and Procedure for DC Measurements

The experimental setup is shown in Fig.1, which is used for measuring DC conductivity of various samples. The sample is placed between the copper electrodes in the furnace under the flow of oxygen gas [6,7]. The copper electrodes are connected to the probes of 6(1/2) digit Keithley-6514 System Electrometer that measures the DC conductivity of the specimens with a resistance up to terra-ohms (TΩ). The measurement of resistance is obtained by varying the temperature [10] from room temperature to the melting point temperature of the polymers at a constant voltage.

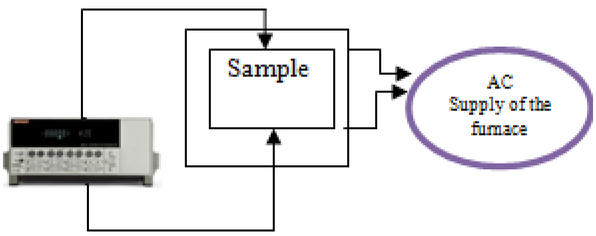

Figure 1: Experimental setup for DC conductivity

The insulation resistance is directly observed from the electrometer for a temperature range from 25°C to 150°C for all the composite materials. The electrical resistivity is obtained by the following formula

$$\rho = (R*A)/l \quad (1)$$

where 'ρ' is the electrical resistivity in S/m (Mho/m), 'R' is the insulation resistance measured in Gigaohms, 'l' is the thickness of the sample in m and 'A' is the area is in sq.m.

$$\sigma = 1/\rho \quad (2)$$

The DC conductivity (σ) in S/m which is the reciprocal of resistivity is calculated by using equation (2). Electrical resistivity and DC conductivity [11, 12] is observed and recorded as per the set-up described in Fig 1.

3. Results and Discussions

A. Evaluation of Insulation Resistance (IR).

The insulation resistance is directly measured from the DC conductivity test with the help of Keithley-6514 system electrometer in which temperature is varied from 25°C to 150°C in the presence of air in the furnace.

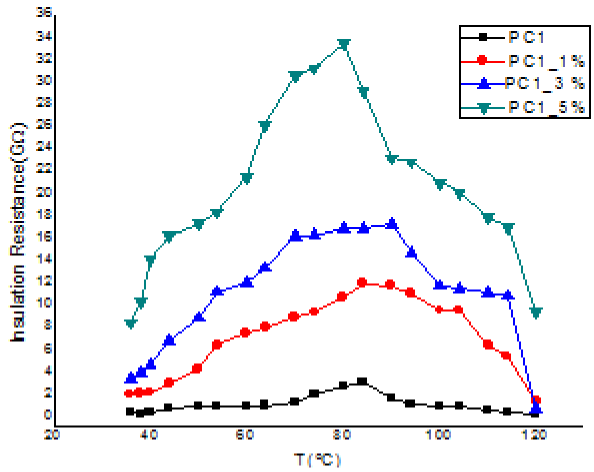

Figure 2: (a)

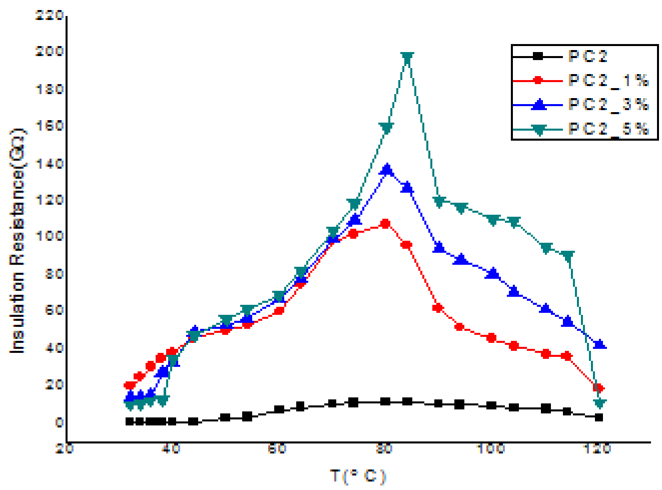

Figure 2: (b)

Figure 2: (a) and (b) Variation of IR vs Temperature(°C) of different composites of PC1 and PC2 polycarbonates.

Table 1: Increase in Insulation Resistance for the derived nano-composites as compare to 'Base Polycarbonate, PC1

Technical parameters	Materials			
	PC1Base	PC1_1	PC1_3	PC1_5
Insulation Resistance @80°C in Giga Ohms	3.01	11.9	16.85	33.42
% Increase in IR after nano-filler incorporation	--	295.34	459.8	1010.3

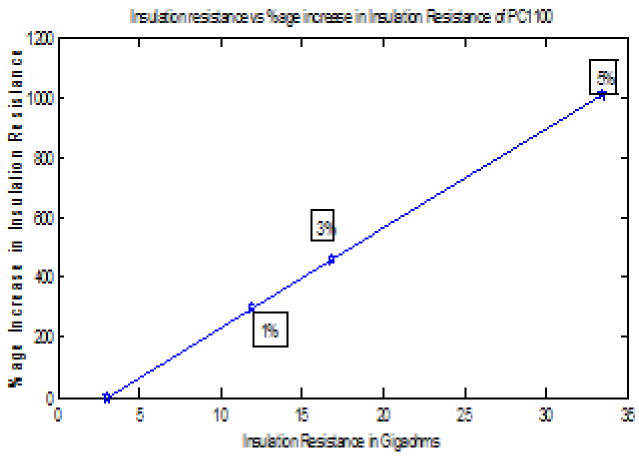

Figure 3: (a)

Table 2: Increase in Insulation Resistance for the derived nanocomposites as compare to 'Base Polycarbonate ,PC2'

Technical parameters	Materials			
	PC2 Base	PC2_1	PC2_3	PC2_5
Insulation Resistance in Giga Ohms @80°C	11.4	107.5	136.3	198.4
%age Increase in I R after nanomodification	--	842.98	1095.61	1640.35

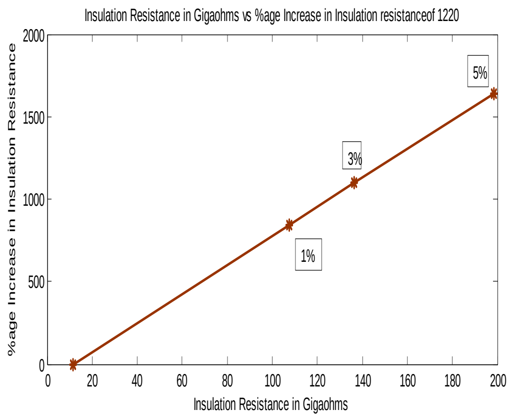

Figure 3: (b)

Figure 3: (a)and (b) Variation of IR vs Temperature(°C) of different composites of PC1 and PC2 polycarbonates.

It can be observed from Fig.2(a)and (b) that the IR gradually increases at lower temperatures and at the mid range of the temperatures, i.e., 60°C - 90°C, the resistance increases upto 3.01GΩ for the PC1 base polycarbonate to 33.42 GΩ for the composites with 5wt% filler, as shown in Table 1. IR increases from 11.4 GΩ for PC2 base polycarbonate to 198.4GΩ for composite with 5wt% filler as shown in Table 2. The percentage of increase in the insulation resistance of both PC1 and PC2 composites with 1%, 3% and 5% are shown in Fig.3(a) and Fig.3(b) respectively. As expected, the insulation resistance decreases as the temperature is increased above 80°C [13,14], which is a normal behaviour of any insulation material.

B. Results of DC Conductivity of various materials

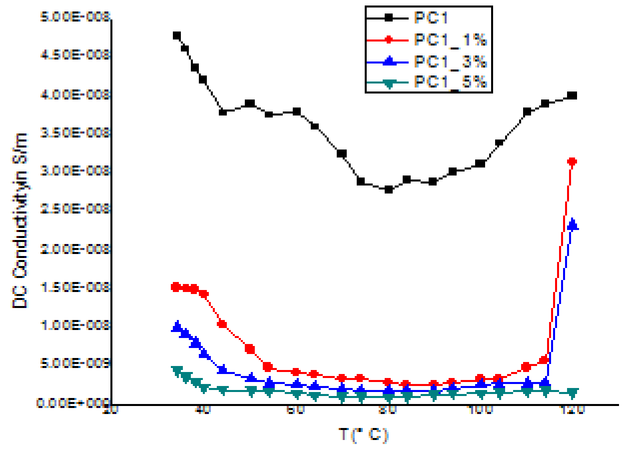

Figure 4: (a)

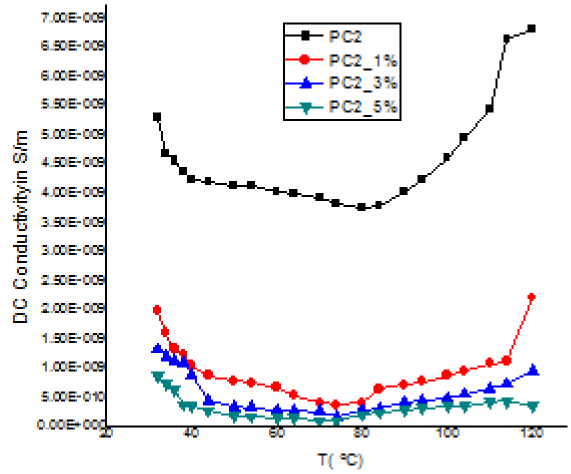

Figure 4: (b).

Figure 4: (a) and fig.4(b) Variation of DC conductivity(S/m) of PC1 and PC2 with the application of temperature °C.

After obtaining the IR by the above procedure, the electrical resistivity has been calculated by using equation(1) and electrical (DC) conductivity by equation (2) respectively. Fig.4(a) and (b) show variation of DC conductivity (S/m) for PC1 and PC2 grades of composite materials at different temperatures. It can be observed that by incorporating the nano-structured amorphous alumina filler material. σ significantly decreases at all temperatures as compared to the base polycarbonates (for both PC1 and PC2 materials),

Table 3: Decrease in DC Conductivity for the derived nano-composites to that of base PC1 polycarbonate

Technical parameters	Materials			
	Base PC1	PC1_1	PC1_3	PC1_5
DC Conductivity @ 80°C	2.77E-08	2.78E-09	1.77E-09	8.92E-10

4. Conclusion

This work describes the decrease in DC conductivity as a function of temperature of polycarbonate matrix materials by incorporating nanostructured amorphous alumina as filler, the filler material of which is well defined and associated with typical set of physical and chemical properties [3,4]. Experimental results indicate that the insulation resistivity, which is calculated from DC conductivity measurements of the derived polycarbonate composites, is increased significantly as compare to its base polycarbonate materials. The results indicate that such composite materials could serve as better support structures, particularly in PCBs in electronic and allied industries [15,16].

Table 4: Decrease in DC Conductivity for the derived nano-composites to that of base PC2 polycarbonate

Technical parameters	Materials			
	Base PC2	PC2_1	PC2_3	PC2_5
DC Conductivity @80°C	3.74E-09	4.17E-10	2.95E-10	2.11E-10

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Author Profile

Sudha.L.K. has received her B.E. in Instrumentation Technology and M.Tech in Electronics from BMSCE, Bangalore. She has 18years of teaching experience from reputed Engineering colleges. She is now working as an Assistant Professor at Bangalore institute of Technology.