Influence of Woven Roving Fiber E-Glass on Electrical Properties of Polyester Composite

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Abstract

The ac conductivity and dielectric permittivity of Polyester filled with different volume fraction of woven roving fiber E-glass prepared by a casting method has been measured, over temperature $(23-100)\ ^{o}C$ and frequency $(40\ kHz - 1\ MHz)$. It was observed that the ac conductivity increases with increasing frequency and temperature, whereas the dielectric permittivity for all samples shows almost independent on frequency, it was increases with increasing temperature and fiberglass volume fraction. The calculated values of the electrical conductivity shows it was obeys power law $A\omega^{s}$ in which the frequency exponent s is in the range of $0.84 < s < 0.98$, and it was decrease with increasing woven roving fiber E-glass.

Introduction

The dielectric properties of polymeric films are of direct interest to both the basic studies of electrical conduction through such films, and their application [1,2]. Extensive observations have been made by several workers to study the molecular motion and the charge carrier migration in variety polymer composites [3-6].

The dielectric properties of the insulator film can be carrying out by measuring simultaneously the capacitance and the dielectric losses of the film over a wide range of frequencies and temperatures. The study of dielectric loss as a function of temperature and frequency, is one of the most convenient and sensitive methods of investigating polymer structure of a polymeric film [2].

Polymer based composites are usually studied for fundamental reasons and practical applications as well. The composites not only combine the advantageous properties of dopant and polymers but also exhibit many new properties that single phase materials do not have [7]. Composites based on polymer resins and reinforced with fibers are an attractive option due to their low cost, low density, biodegradability and low environmental concerns. Fiber reinforced polymer matrix composites are being considered for use in several industrial applications with particular interest in the car industry [8].

In this paper the dielectric permittivity and ac conductivity behaviour of the undoped Polyester (PS) and the doped PS with $6, 12, and\ 19\ \%$ of woven roving fiber E-glass has been investigated over the frequency $40\ kHz - 1\ MHz$, and temperature from 23 to $100^{o}C$.

Theory

In an alternating ac field, the dielectric permittivity is a complex quantity ε^{*}, which consist of two combinations, the real part which is known as the relative permittivity or dielectric constant ε' and imaginary part called the dielectric loss or dissipation factor ε'' [9]. The complex dielectric permittivity ε^{*} as a function of angular frequency ω of the measuring electric field can be represented as [10]:

$$\varepsilon^{*}(\omega) = \varepsilon'(\omega) - i\varepsilon''^{(\omega)} \quad \text{.................................(1)}$$

The dielectric permittivity ε' of sample is evaluated from the capacitance C_s measured using equation:

$$\varepsilon' = \frac{C_s d}{\varepsilon_o A} \quad \text{..(2)}$$

where ε_o is permittivity of free space, A and d are the effective cross-sectional area and thickness of the sample respectively.

The dielectric loss factor ε'' can be calculated from measurement value ac conductance by [11]:

$$\varepsilon'' = \frac{\sigma_{ac}}{\varepsilon_o \omega} \quad \text{...(3)}$$

here σ_{ac} represents the ac-conductivity of the polymer sample which arises from the motion of charge carriers through the polymer.

The general formula of σ_{ac} as a function of polymer conductance G_s is given by [12]:

$$\sigma_{ac} = \frac{d\ G_s}{A} \quad \text{......} (4)$$

Then the loss tangent $tan\delta$ can be determined from the values of $\varepsilon'$and ε'' using this equation:

$$tan\delta = \varepsilon''/\varepsilon' \quad \text{......} (5)$$

where δ is the phase angle between the electric field and the polarization of the dielectric.

In general the complex conductivity σ^* was written as:

$$\sigma^* = \sigma'(\omega) + i\sigma''(\omega) \quad \text{......} (6)$$

where σ' and σ'' are the real and imaginary parts of the conductance. The real part of conductivity σ' has been often analyzed separated in two different components:

$$\sigma' = \sigma_{dc} + \sigma_{ac} \quad \text{......} (7)$$

The dc conductivity σ_{dc} usually described by hopping models of electrons near the Fermi level [13]. The term hopping refers to the sudden displacement of charge carriers from one position to another neighboring site and in general includes both jumps over a potential barrier and quantum mechanical tunneling [14]. The dc conductivity σ_{dc} is frequency independent conductivity, while the ac conductivity σ_{ac} is frequency dependent and follows a universal power law in the form of [15]:

$$\sigma_{ac} = B\omega^s \quad \text{......} (8)$$

here B is dependent on temperature, and the frequency exponent s lying between 0 and 1, can be determined from the linear slope of $log\sigma_{ac}$ versus $log\omega$.

Experimental Detail

Polyester as matrix material was used in the experiments to prepare the polymer matrix composite. The rate of polymerization for this resin is too slow. For practical purpose the catalyst Methel Ethel Keton proxide MEKP in a proportion of $0.5gm$ for each $100gm$ of the resin, and accelerator Cobalt napthenate catalyst in a proportion of 0.1gm for each $100gm$ of the resin are used.

The sample of Polyester doped with (0, 6, 12, and 19) % of woven roving fiber E-glass of thicknesses $d = 3$ mm has been prepared using solution cast technique. After preparation of the resin with the desired volume fraction it was cast in the round glass plate, and was left out for 24 hours at room temperature to complete setting. Finally, it was put in furnace at 60^oC for four hours post curing.

In order to obtain a good contact for electrical measurements, the prepared samples of radius 1.5 cm have been coated with silver materials on both surfaces. The silver coated samples sandwiched between the two similar aluminum electrodes governed by a screw to minimize the parasite capacitance induced by the presence of air interstices at the interfaces between the sample and the electrodes. The whole assembly was placed in a temperature controllable isolated chamber, and the temperature was measured by Chromel-Alumel thermocouple using a digital multimeter with an accuracy of $\pm 1^oC$.

Results and Discussion

The electrical parameters (dielectric permittivity ε', dielectric loss ε'' and ac conductivity σ_{ac}) were calculated from conductance G_s and capacitance C_s which were measured using the Programmable Automatic Precision LCR meter type PM6036, in the temperature range $(23 - 100)^oC$ over the frequency range from 40 kHz to 1 MHz.

Fig.(1) shows the dielectric spectra of polymer composites at different temperature for pure Polyester, and 19% doped with woven roving fiber E-glass. In general, the variation of dielectric permittivity with temperature is different for nonpolar and polar polymers. For nonpolar polymers the dielectric permittivity is independent of temperature; but in the case of strong polar polymers the dielectric permittivity increases as the temperature increases [16]. The independent trend of dielectric permittivity with frequency could be due to the nonpolar behaviour of Polyester chains [8].

The dielectric permittivity of composites increases as the temperature increases, due to the non-polar behavior of the Polyester.

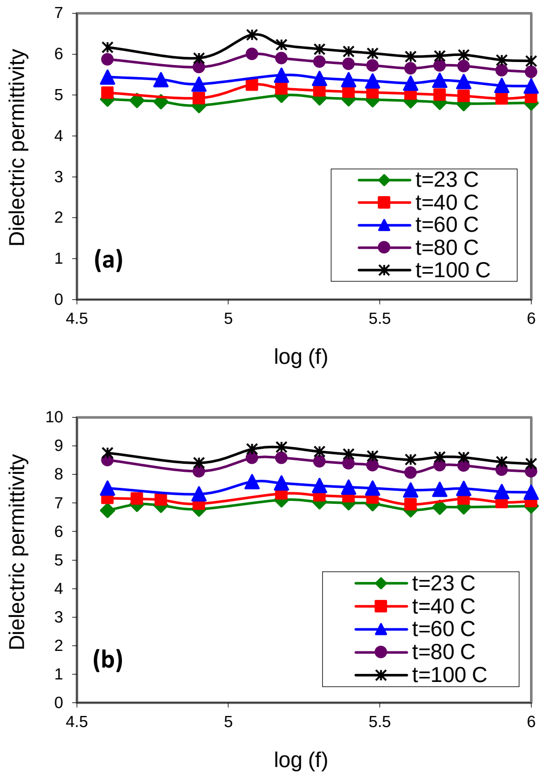

Fig.(1) Variation of dielectric permittivity of: (a)pure Polyester, and (b)19% doped with woven roving fiber E-glass, as a function of frequency at different temperatures.

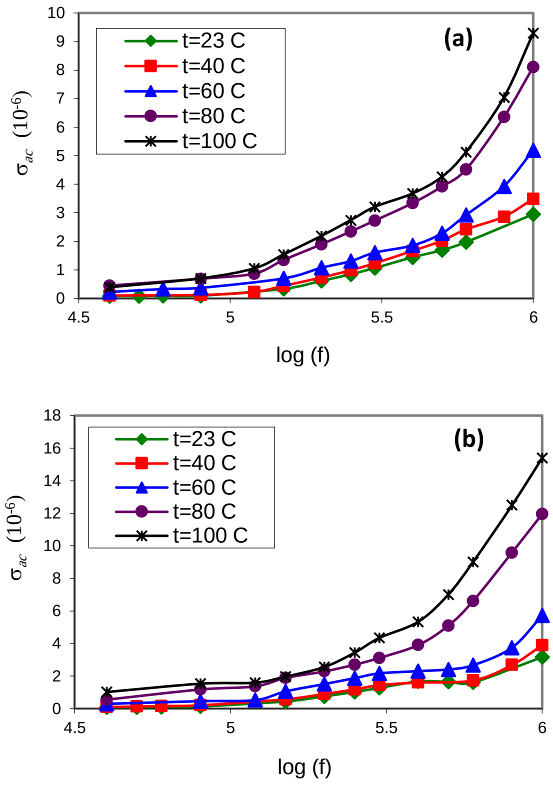

Fig.(2) Variation of ac conductivity of: (a)pure Polyester, and (b)19% doped with woven roving fiber E-glass, as a function of frequency at different temperatures.

The frequency dependence of the ac conductivity σ_{ac} for different values of temperatures for pure Polyester, and 19% doped with woven roving fiber E-glass, are shown in Fig.(2). The frequency dependent conductivity is caused by the hopping of the charge carriers in the localized state and also due to the excitation of charge carriers to upper states in the conduction band [3,17].

According to the obtained results, we observed that the ac conductivity σ_{ac} decrease with increasing fiberglass contents and temperature, while it seems to be increases with increasing frequency.

Polyester resins are non-conductors, having relatively low dipolar characteristics, and providing high dielectric strength and surface resistivity. These composites find extensive use in the insulation of motor windings, encapsulation of electrical components, fabrication of printed circuit boards, high voltage standoff insulators, switch boxes, and miscellaneous equipment used on high-voltage transmission lines [18].

The variation of the ac conductivity of the Polyester composite with respect to temperature, at frequency $400\,kHz$, for different $wt\%$ of woven roving fiber E-glass, are shown in Fig.(3). The decrease trend of ac conductivity for all samples with temperature, and fiberglass volume fraction are observed.

The variation of dielectric loss factor with temperature for different volume fraction of woven roving fiber E-glass at constant frequencies are show in Fig.(4). The dielectric loss factor for all samples decrease with temperature, and fiberglass volume fraction.

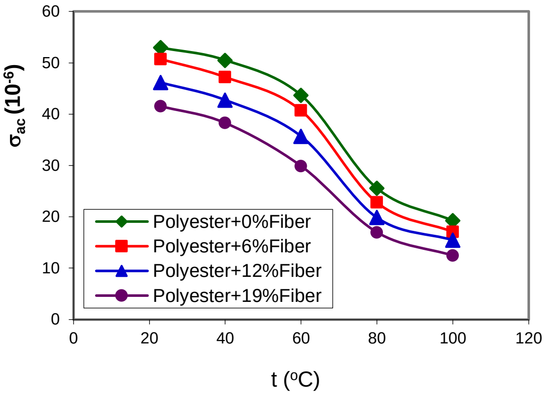

Fig.(3) Ac conductivity of pure Polyester, and doped with different volume fraction of woven roving fiber E-glass, as a function of temperature at constant frequency (400kHz).

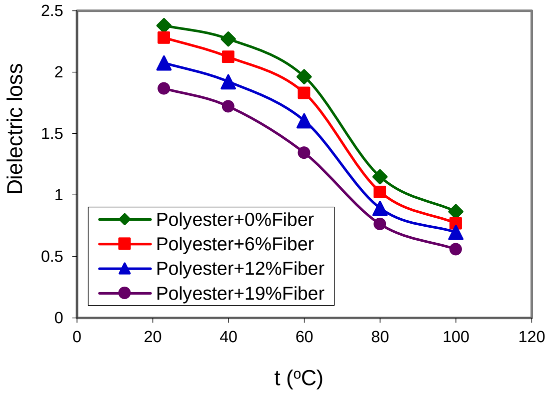

Fig.(4) Dielectric loss of pure Polyester, and doped with different volume fraction of woven roving fiber E-glass, as a function of temperature at constant frequency (400kHz).

The frequency and temperature dependent of ac conductivity is caused by the hopping of the charge carriers in the localized state and also due to the excitation of charge carriers to upper states in the conduction band [3,17]. The conductivity obeys the empirical universal power law relation [19]:

$$\sigma'(\omega,T) = \sigma_{dc}(T) + B\omega^{s} \quad \text{.............................} (9)$$

Neglecting the dc part $\sigma_{dc}(T)$ in the above relation the variation of the exponential factor s was calculated from slope of the best-fitted line of the plot between logarithm of ac conductivity $log\big(\sigma_{ac}(\omega,T)\big)$ and logarithm of angular frequency $log(\omega)$. The variation of s of composite as a function of temperature for different volume fractions of woven roving fiber E-glass are shown in Fig.(5). The variation of exponent s with temperature gives information on the specific mechanism involved. Depending on the obtained results s is weakly function of temperature. The value of s was found to be in the rang 0.84 to 0.98 for all composites.

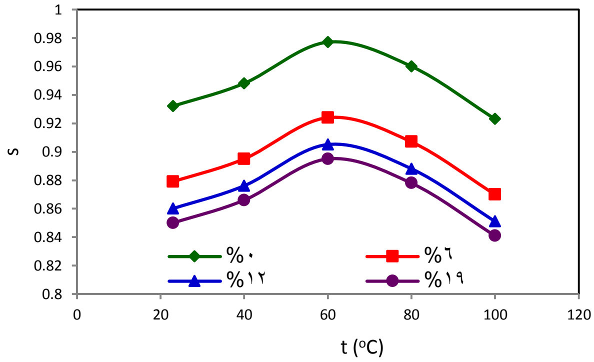

Fig.(5) The* variation of exponent *s* with temperature *for Polyester-woven roving fiber E-glass composite.

Conclusions

Polyester-woven roving fiber E-glass composite with different volume fraction of fiber glass have been prepared by casting method. The effect of fibreglass volume fraction, frequency, and temperature, on ac conductivity and dielectric permittivity of composite samples are investigated. The dielectric permittivity seems to be independent on frequency for all composites, whereas it was slightly increases with increasing temperature and fiberglass volume fraction. This behavior was attributed to the nonpolar nature of the Polyester. The ac conductivity was found to be increase with increasing frequency, temperature and fiberglass volume fraction. The ac conductivity obeys the power law $\sigma(\omega) \propto \omega^{s}$, and the calculated values of the frequency exponent s is in the range of $0.84 - 0.98$, and it was decrease with increasing woven roving fiber E-glass.

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الخلاصة

تم حساب توصيلية التيار المتناوب و السماحية العزلية للبولي استر المملوء بتراكيز مختلفة من حصيرة المجدولة من الياف E الزجاجية المحضرة بطريقة الصب، لمدى من درجات الحرارة (٢٣-١٠٠) درجة المئوية و ترددات (1MHz−40kHz). لوحظ نقصان السماحية العزلية بزيادة التردد و درجة الحرارة، اظهرت النتائج لجميع العينات عدم اعتماد التوصيلية التيار المتناوب على التردد، حيث انها تزداد بزيادة درجة الحرارة و تركيز الالياف الزجاجية. القيم المحسوبة للتوصيلية الكهربائية اظهرت توافقها مع قانون القوة $A\omega^s$ و التي فيها اس التردد s هو في مدى من $0.84 < s < 0.98$ ، و تقل قيمتها بزيادة تركيز الالياف E الزجاجية.