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Evaluation of dielectric behavior of bio-waste reinforced polymer composite

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Abstract

Coir dust reinforced polymer composites are prepared with epoxy resin as the matrix. The dielectric parameters (relative permittivity ε', dielectric loss ε''), AC conductivity σ, and resistivity ρ of pure epoxy resin and composites with different weight percent of coir dust were obtained in a frequency range of 100 Hz to 1 MHz, and temperature range of 30–150°C. The experimental results show that ε', ε'', and σ are increased and ρ is decreased with the addition of coir dust in epoxy resin. It is also observed that the dielectrical properties of the composites showed a strong dependence on frequency and temperature. The ε' and ε'' increases with increasing temperature because of greater movement of the dipole molecular chains and decreases with increasing frequency due to the orientation polarization. The conductivity of the composite is increased, and the resistivity of composite is decreased with increasing frequency.

Keywords

Composite materials, orientation polarization, dielectric loss, conductivity, resistivity, dielectric relaxation, epoxy resin

Introduction

In recent years, the incorporation of natural fibers as reinforcing agent in polymer composite has gained increasing interest, which enhance optimal utilization of natural resources, and particularly, of renewable resources. Natural fibers have proven to be suitable reinforcement materials for composite, thanks to a combination of good mechanical, high electrical (insulating), impact resistance, good thermal properties, acoustic insulating properties, and environmental advantages such a renewability and biodegradability as comparable to synthetic fiber reinforced polymer composites.[1–3] Hence, for these reasons it has not been surprising that the use of natural materials in the production of composites has gained significant importance both in technical applications such as in automotive industry, as well as in the electronics industry for its dielectric and insulating properties in the use of capacitors, microelectronic components (such as transistors and ICs), and safe insulators for low to moderate voltages (hundreds of volts).[4–7]

The aim of this work is to analyze the dielectric properties (relative permittivity and tangent loss), conductivity, and resistivity of (bio-waste) coir dust reinforced polymer composite materials. The electrical response of a normal dielectric can be described by its conductivity, resistivity, dielectric constant, and loss factor. The effective utilization of polymer composites depends on the ability to disperse the fibers homogeneously throughout the matrix.[8] The characteristics and performance of the composites are also strongly affected by the interface properties.[9] The different wt% of the coir dust fiber reinforced polymer composites are given in Table 1.

Experimental details

Materials

Epoxy LY556, chemically belonging to the 'epoxide' family, is used as the matrix material. The hardener with IUPAC name NN0 = bis(2-amineethylethane-1,2-diamin) used with the epoxy has the designation

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Table 1. Different wt% percentages of the coir dust in epoxy resin

Designation	Composition
ECD1 (sample A)	Pure epoxy
ECD2 (sample B)	Epoxy + 10 wt% coir dust
ECD3 (sample C)	Epoxy + 20 wt% coir dust
ECD4 (sample D)	Epoxy + 40 wt% coir dust
ECD5 (sample E)	Epoxy + 60 wt% coir dust

HY-951.The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Resin and hardeners are mixed in a ratio of 8:1 by weight as recommended. Density of the epoxy resin system is 1.1 g/cc, and the density of coir dust, which is used as reinforcement, is 1.2 g/cc.

Fabrication of composite by hand lay-out method

The coir dust was mixed with the epoxy, by stirring at room temperature and disc shaped samples (of 10 mm diameter and 2.5 mm thickness) are prepared by uniaxial pressing at 1.5 ton load.

Dielectric analysis

Dielectric measurements were carried out with a solartron 1296 Dielectric Interface Instrument allowing measurements over the temperature range from 30°C to 150°C and frequency range from 100 Hz to 1 MHz. In dielectric analysis, the upper and lower surface of the sample are coated with silver paint for the purpose of conductance and the sample is placed between the two Al parallel electrodes. A sinusoidal signal is applied, creating an alternating electric field. This electric field produce polarization in the sample, which oscillates at the same frequency as of the applied electric field, but has a phase angle shift δ. This phase angle shift is measured by comparing the applied voltage to the measured current, which is separated into capacitive and conductive components.[10,11]

The dielectric constant, dielectric loss, conductivity, and resistivity are determined as follows:

$$\text{Dielectric constant } K = C'/C$$

where C' (pF) is measured capacitance and C (pF) is calculated using the formulae:

$$C = \varepsilon_0 (A/d)$$

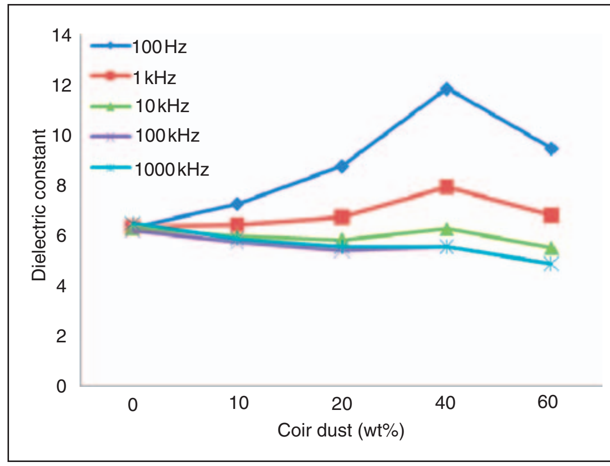

Figure 1. Frequency dependence of dielectric constant at room temperature for different amount of coir dust.

where A is the area of the electrode (mm^2), d the thickness of the sample (mm).

The dielectric loss is given by, $\tan \delta = G(S)/w\ C'(F)$, $w = 2\pi f$, where f is the measuring frequency and $G = G_0(R - R_0)$.[1]

Results and discussion

Figure 1 gives the variation of dielectric constant with the amount of coir dust for different frequencies at room temperature. The figure shows that the K-value increases with increasing coir dust amount, the reason may be that the absorption of moisture (due to humidity, as the experiment is conducted at 90% realative humidity condition). Figure 2 shows the variation of dielectric constant (K) with frequency at different temperatures for samples A, B, C, D, and E, respetively. From the figure it is clear that dielectric constant decreased with increasing frequency at constant temperature, and increased with increasing temperature at constant frequency. Low frequency and high temperature have more prominent effect on the dielectric constant. Decreasing nature of the K-value with increasing frequency is due to the dielectric relaxation, which is the cause of anamalous dispersion. At higher frequencies the orientation of polar molecules along the direction of the applied electric field is disturbed.[12]

Figure 3(a)–(e) shows the variation of dielectric constant with temperature at different frequencies for samples A, B, C, D, and E, respectively. From the figure it is clear that the value of K increases with increasing temperature at constant frequency. The increase in K-value with increasing temperature is due to the greater freedom of movement of dipole molecular chains. With increasing temperature the polarization increases and hence the dielectric constant also increases.[13]

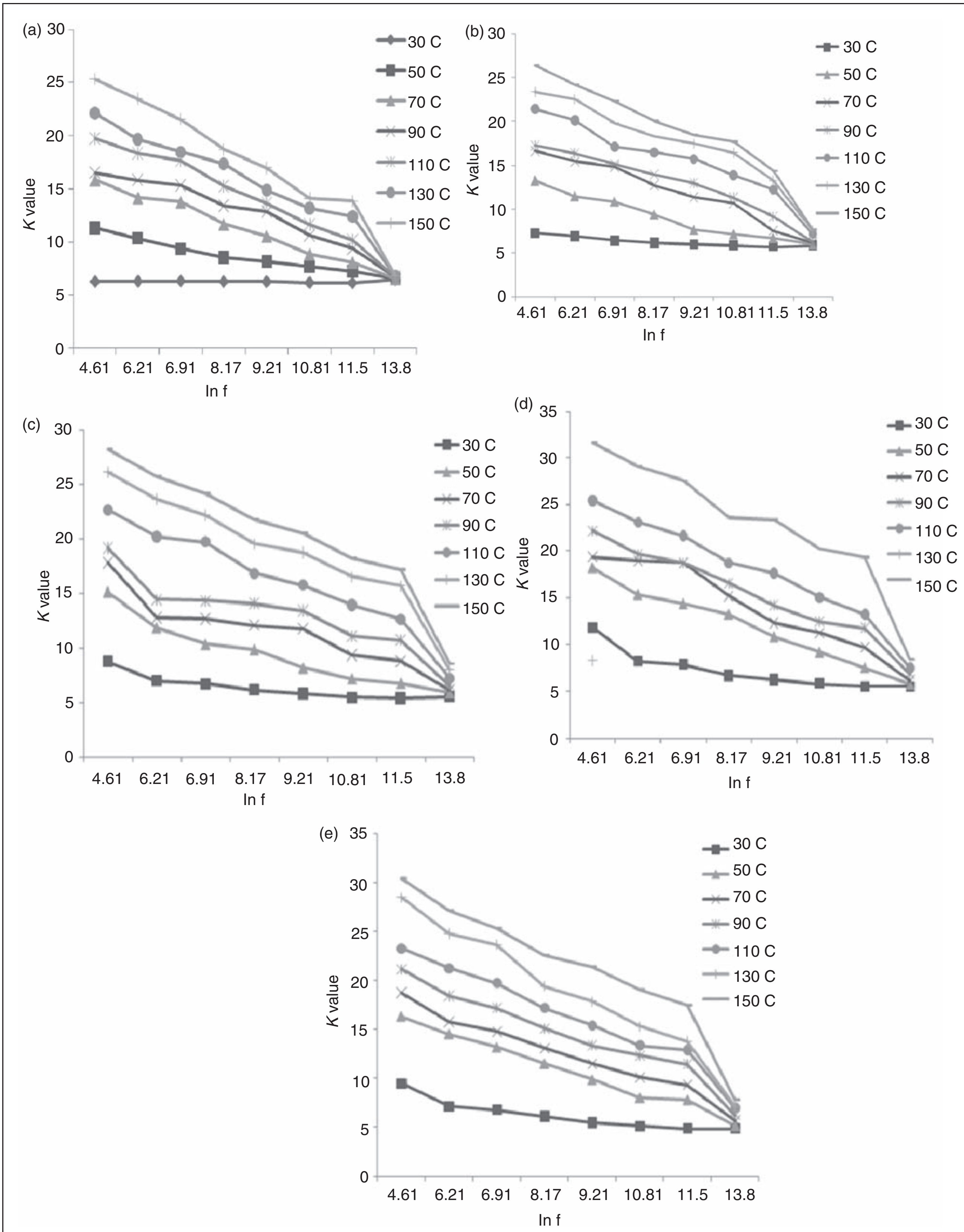

Figure 2. Frequency dependence of *K*-value at different temperatures for (a) sample A; (b) sample B; (c) sample C; (d) sample D; and (e) sample E.

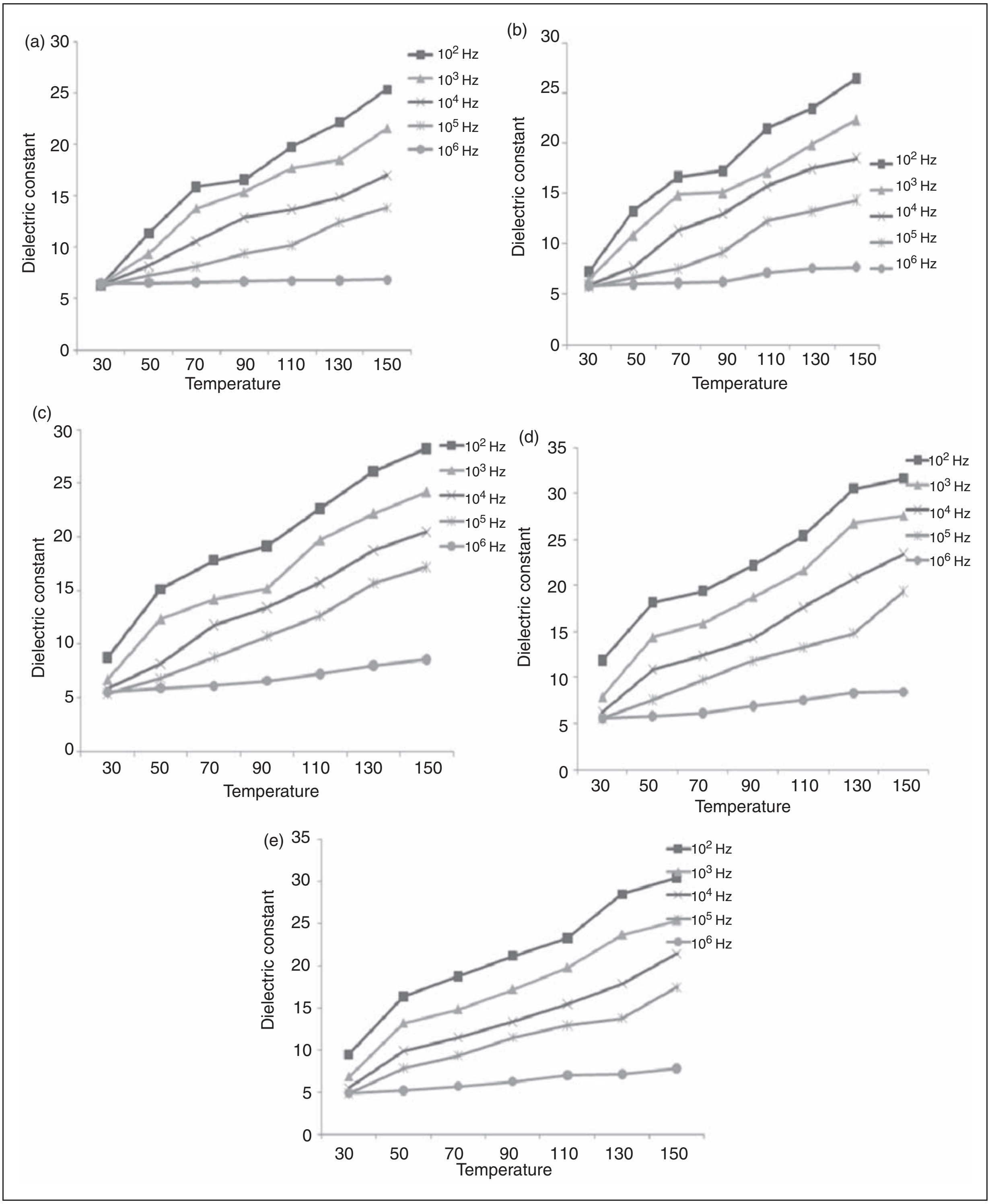

Figure 3. Temperature dependence of *K*-value at different frequencies for: (a) sample A; (b) sample B; (c) sample C; (d) sample D; and (e) sample E.

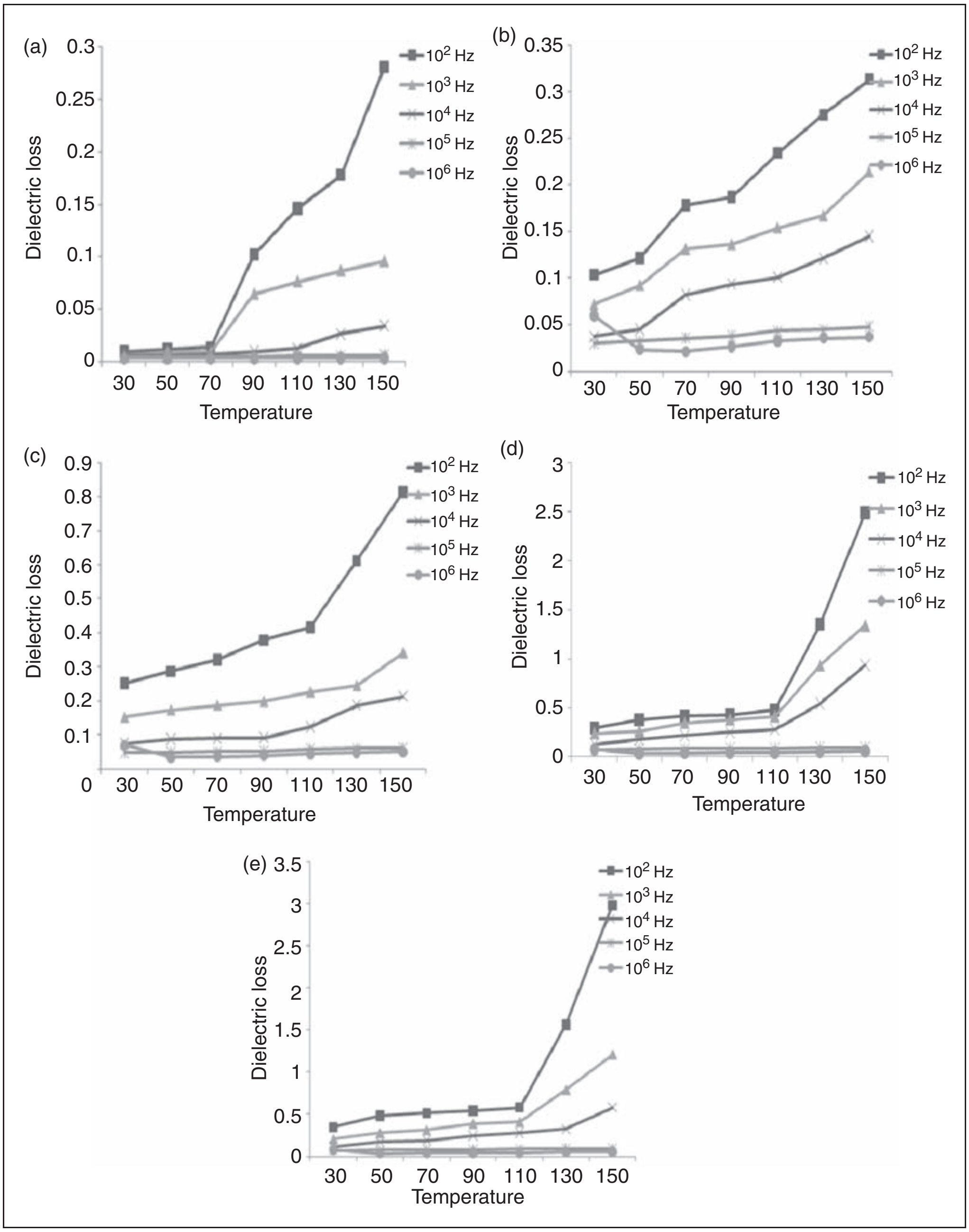

Figure 4. Temperature dependence of loss factor at different frequencies for: (a) sample A; (b) sample B; (c) sample C; (d) sample D; and (e) sample E.

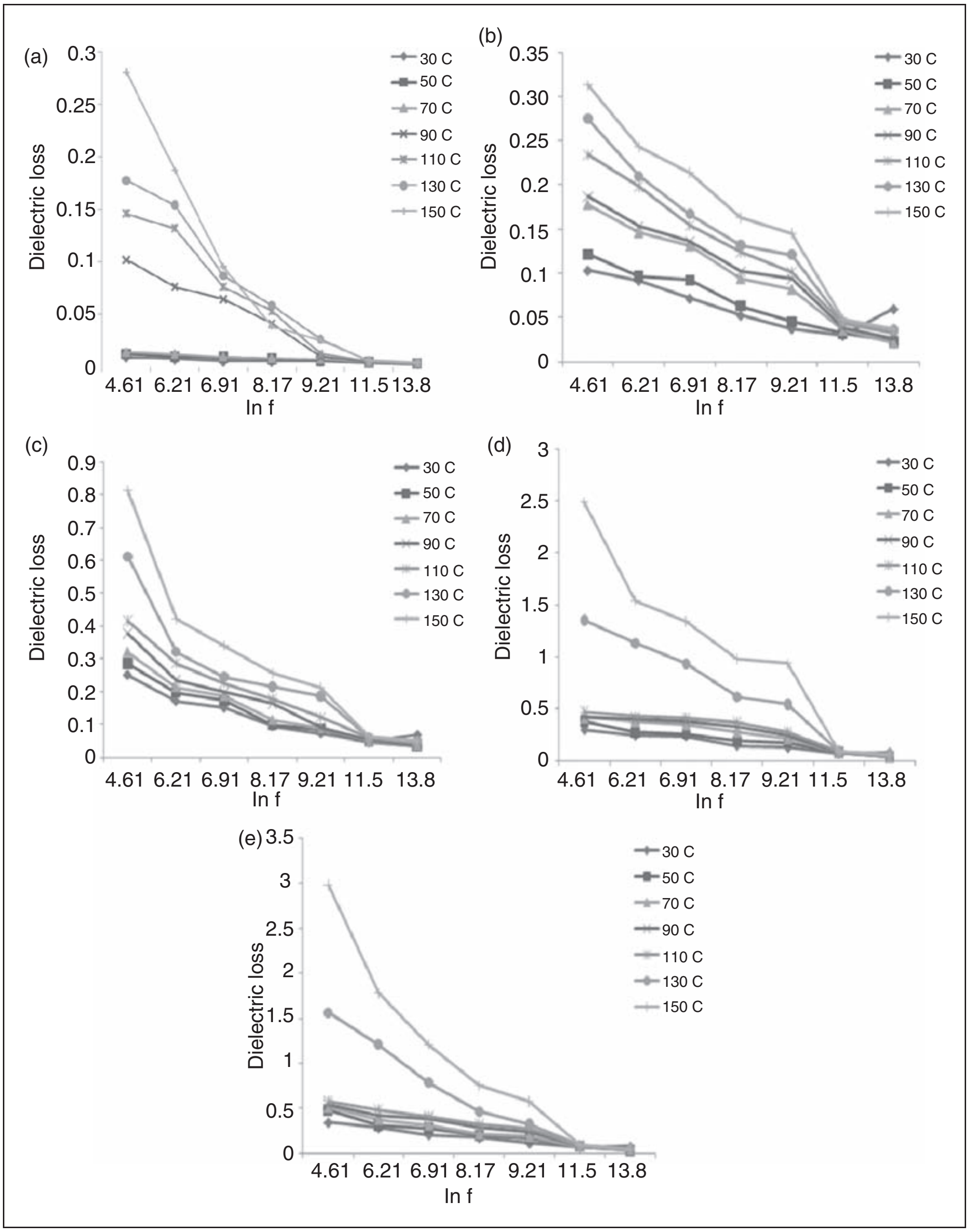

Figure 5. Frequency dependence of loss factor at different temperatures for: (a) sample A; (b) sample B; (c) sample C; (d) sample D; and (e) sample E.

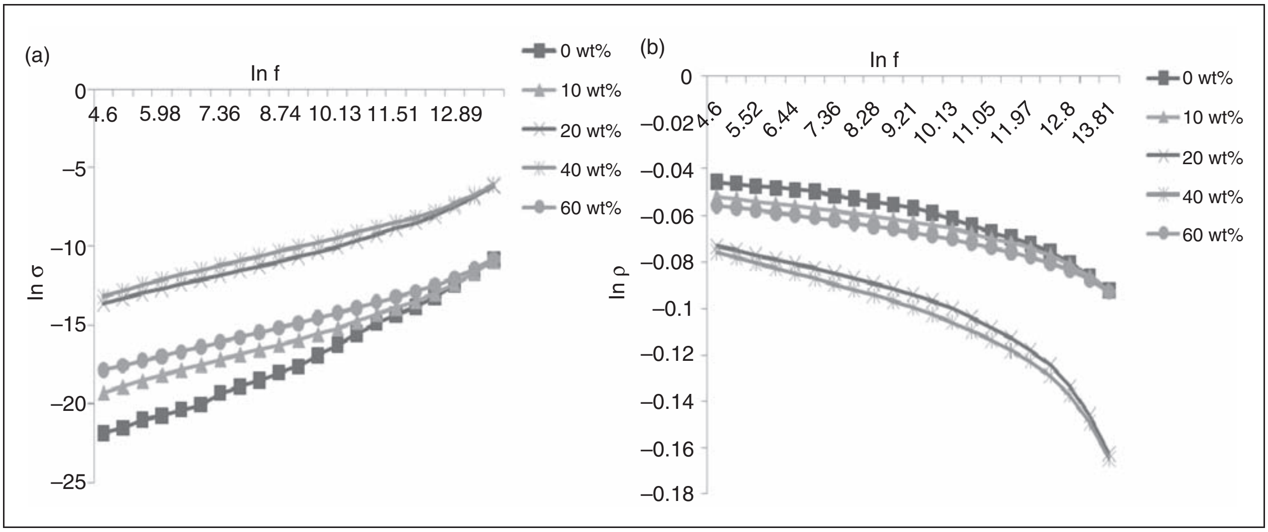

Figure 6. Frequency dependence of: (a) conductivity and (b) resistivity.

Figure 4(a)–(e) shows the variation of the dielectric loss with temperature at different frequencies for samples A, B, C, D, and E respectively. From the figure it is clear that dielectric loss increases with increasing temperature at lower frequencies; the reason may be the contribution of AC conductivity; but at higher frequencies the increment in the dielectric loss is negligible.

Figure 5(a)–(e) shows the variation of dielectric loss with frequency at different temperatures for samples A, B, C, D, and E, respectively. From the figure it is clear that the loss factor decreases with increasing frequency at constant temperature, the decrement in the loss factor for high temperature at low frequency is more prominent which is the usual behavior of many dielectric materials.[14]

Figure 6(a)–(b) shows the variation of AC conductivity and resistivity with frequency at different weight percentage of coir dust. From the figure it is clear that the conductivity of the material increases with increasing frequency at room temperature. It is also observed that at 40 wt% coir dust the A.C conductivity is more pronounced. The resistivity of the material is decreases with increasing frequency at room temperature.

Conclusion

Dielectric properties (relative permittivity and loss factor), AC conductivity, and AC resistivity of pure epoxy resin and composites with different amount of coir dust reinforced polymer composite have been studied in the frequency range 100 Hz to 1 MHz and in the temperature range 30–150°C. The experimental results indicate that the dielectric constant and dielectric loss factor decreases with increasing frequency, may be due to the orientation polarization and increases with increasing temperature due to greater movement of polar molecular dipole. At low frequency and high temperature this effect is more prominent on dielectric constant and dielectric loss.The AC conductivity has increased and AC resistivity has decreased with increasing frequency, at room temperature and maximum variation of conductivity and resistivity with frequency is observed at 40 wt% coir dust reinforced composite.

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