Electrical properties of natural fiber graft co-polymer reinforced phenol formaldehyde composites

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The electrical properties of Hibiscus Sabdariffa grafted co-polymer reinforced phenol formaldehyde composite were studied with reference to dielectric constant, dielectric dissipation factor, dielectric loss factor and volume resistivity. The dielectric constant was found to decrease with frequency that was due to decrease of polarization. The dissipation factor showed first increase and then decrease with increase in frequency at different voltage. The volume resistivity of composite also decreased with frequency. The dielectric loss factor was observed to be high at lower frequency which was due to polarization of fiber at lower frequency.

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1. Introduction

Composites material reinforced with cellulosic fibers have received interest in recent years due to their biodegradability, better mechanical properties, low density and non – toxicity [1,2]. The modification of cellulosic fiber through graft co-polymerization has been reported by various workers [3-7]. Natural fibers such as flax, jute etc. hold good reinforcement capability when mixed with polymeric matrix [8,9]. It has been observed that reinforcing power of natural fiber reinforced composites have received much more advantages for engineering, automobile, aerospace, marine, infrastructure, military etc.

Fiber reinforced plastic materials act as effective insulators and also provide mechanical support for field carrying conductors. The incorporation of fibrous reinforcements in polymeric matrices leads to composite materials having very good mechanical properties and electrical application. They can be used as terminals, connectors, industrial and house hold plugs and printed circuit boards. The electrical application of composite material makes the study of composite materials important.

The electrical properties such as volume resistivity, dielectric constant of some natural fibers and composites have been studied worldwide [10,11]. The electrical properties of pineapple fiber reinforced polyethylene composite were reported to have increased orientation and interfacial polarization [12]. It has been observed that dielectric constant of jute fiber composite is higher than that of glass fibers because of higher water uptake of jute fiber than glass fiber [13]. The study of dielectric constant and dielectric loss as a function of temperature and frequency is one of the most convenient and sensitive methods of studying polymeric structure. The physical structure of polymer composites is of great importance in determining the dielectric behavior [14]. The dielectric properties of polymer composite materials have been studied to modify the properties of polymer system for practical applications. The electrical properties of sisal fiber reinforced low density polyethylene composite have been compared with that of carbon black and glass fiber filled low density polyethylene composite [15-18]. These studies have considered the effect of frequency, fiber content and fiber length. The dielectric constant increased steadily with increasing fiber content for all frequencies in the range of 1 to 10^7 Hz. The relationship between water absorption and dielectric behavior on polyester matrix composite of glass and jute fiber showed that dielectric constant of jute fiber composite is higher than that of glass fiber because of higher water uptake on jute fibers than glass fibers [19]. The electric properties of banana fiber reinforced phenol formaldehyde composite have been studied with respect to fiber loading, fiber treatment and hybridization with glass fibers [20]. The variation of dielectric dissipation factor (tan δ) of sisal fiber epoxy composites at different temperature and frequencies has also been reported [21]. This study observed that dielectric dissipation factor increased with temperature and decreased with frequency.

The dielectric loss peaks were observed at about 1 kHz at high temperature in composite materials, which may be due to the temperature glass transition in polyester. The dielectric loss factor increased with temperature, particularly at lower frequencies at which dielectric loss due to chain motion of polymer was more effective due to glass transition temperature of the polymer. The electrical properties of banana fiber reinforced phenol formaldehyde composite have been studied with respect to fiber loading, fiber treatment and hybridization with glass fibers [22]. The variation of thermal conductivity and thermal diffusivity of banana fiber reinforced polyester composite caused by addition of glass fiber have also been studied [23]. These studies found that the thermal conductivity of composites increased when compared to matrix. The another study highlighted the effect of fiber length and fiber orientation angle on the thermal conductivity of short carbon fiber reinforced composite materials [24]. It has been observed that the thermal conductivity of the composite increased with fiber length but decreased with fiber orientation angle with respect to the measured direction.

The available literature thus revealed that there is no study on the electrical properties of Hibiscus Sabdariffa grafted co-polymer reinforced composite, despite of its great significance in the electrical and electronic industry for making panels, switches, insulators etc. Therefore the aim of the present research work is to evaluate the electrical properties of Hibiscus Sabdariffa grafted co-polymer reinforced phenol formaldehyde composite were studied with respect to dielectric constant, dielectric dissipation factor, dielectric loss factor and volume resistivity.

2. Experimental

2.1 Material

Hibiscus Sabdariffa fiber was obtained from the Department of Agronomy, Chaudhary Sarwan Kumar Himachal Krishi Vishwavidyalaya, Palampur, Himachal Pradesh, India. The chemical ethyl acrylate (Merck, India), acrylonitrile (S.D. Fine), ceric ammonium nitrate (Merck, India) alcohol (Tedia, USA) and dimethylformamide (S.D. Fine) were used. Electronic balance (Lakshmi Samson, India) was used for weighing. Composite was prepared in compression molding machine (Santec, India Ltd). Electrical properties were determined using Programmable Automatic RCL meter, model PM 6306, Fluke, Netherland make.

2.2 Methods

2.2.1 Preparation of graft co-polymer of binary monomers (EA-AN)

0.5 gram of Hibiscus Sabdariffa fiber was activated by immersing in 100 ml of deionized water for 24 hours. Ceric ammonium nitrate (CAN) and HNO_3 mixture were slowly added to the reaction flask followed by monomers EA and AN under optimum condition.

The reaction flask was then stirred continuously for definite time interval at particular temperature. After the completion of the recation, the graft co-polymer was soxhlet extract with alcohol and DMF to remove homopolymers such as poly (EA) and Poly (AM). The graft co-polymer was then dried at 50^0C until constant weight was obtained. The percentage grafting was calculated as follow:

$$Grafting\ yield\ (\%) = \frac{W_w - W_1}{W_1} \ x\ 100$$

where W_w and W_1 are the weights of grafted and original sample, respectively.

The graft co-polymer having highest value of P_g can be used for composite preparation.

2.2.2 Preparation of composite material

The co-polymer grafted fiber was mixed with phenol formaldehyde resin in ratio of (12.7:87.3). The mixture was then placed in the mold of 40-80 mm (Length), 5x5 mm (Cross section) dimension. The sample was kept for curing at 120^0C for 10 minutes at 400 Kg/cm^2 pressure. Then it was kept out and subjected for different electrical properties.

2.2.3 Measurement of electrical properties

The capacitance, resistance, dissipation factor and dielectric loss factor were measured directly by using RCL meter by varying the frequencies at room temperature. The square samples of thickness 0.5 cm, length 1.4 cm and breadth 1.4 cm were used for the study. The test samples were fixed between two electrodes. The dielectric constant and dissipation factor were measured in the frequency range 100 Hz to 1 MHz and volume resistivity was measured in frequency range 2000 Hz to 1 MHz. The electrical properties were determined as follow:

2.3 Dielectric constant (ε^1)

It was calculated from the capacitance using equation

$$\varepsilon^1 = ct/\ \varepsilon_o A$$

where ε_o is permittivity of air (8.85 x 10^{-12} Fm^{-1}), C is capacitance with dielectric, A is the area of cross section of the sample; t is the thickness of the sample.

2.4 Volume resistivity (ρ)

It was calculated from the resistance using following equation as

$$\rho = RA/\ t$$

where

A is the area of cross section of the sample, R is the resistance, t is the thickness of the sample.

2.5 Dielectric dissipation factor (tan δ)

It was determined as follow

$$\tan(\delta) = \varepsilon^{II}/\ \varepsilon^{I}$$

where ε^{II} is the dielectric loss.

3. Result and discussion

Fig. 1 shows the variation of dielectric constant with log frequency. It is evident from the figure that the dielectric constant of composite decreases with increase in frequency at various voltages. At higher frequency the rotational motion of polar molecules of dielectric is not sufficient for the attainment of equilibrium with the field and hence dielectric constant decreases with increase in frequency [25]. The dielectric constant of material depends upon the polarizability of the material. The Greater is the polarizability of the molecule, higher will be the dielectric constant. The dielectric constant of polymer materials depends on interfacial, dipole and atomic polarization [12]. The electronic and atomic polarization occur at high frequency is due to presence of polar group in the material. The interfacial polarization arises due to heterogeneity, which is highest at lower frequency.

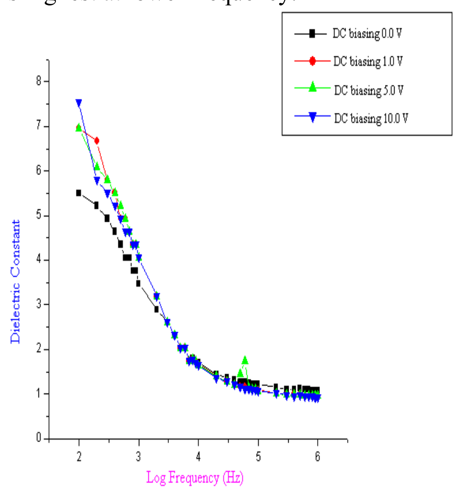

Fig. 1. The variation of dielectric constant of composite material as a function of logarithm of frequency at different voltage.

Fig. 2 shows the variation of dielectric dissipation factor with log frequency. It is clear from the figure that dissipation factor increases initially with increase of frequency and decreases with increasing frequency. These results are similar to the study conducted by Chand et. al. [21].The curve indicates ionic migration conduction at low frequency. The peak is associated with a molecular dipole rotation and occurs when the rotational mobility of molecule rotation can just keep up with the alterations of electric field [26]. The dissipation factor is maximum at 3500 Hz to 4000 Hz.

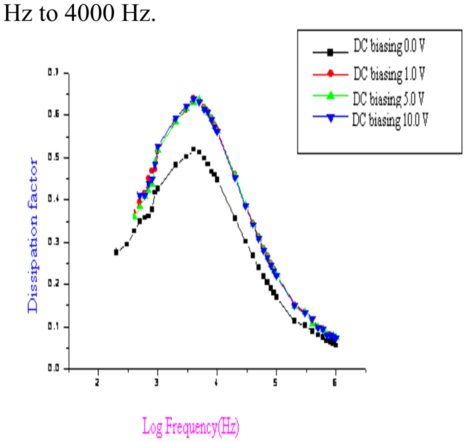

Fig. 2. Dissipation factor (Tan Delta) versus log frequency curves of composite material at different Voltage.

The volume resistivity as function of log frequency for fiber reinforced phenol formaldehyde is given in Fig. 3. It is observed that the volume resistivity of the composite decreases with increase in frequency at various voltages. This is due to the reason that with increase in frequency, interfacial polarization occurs because of heterogeneity of the system. It is observed that moisture content in the fiber increase the conductivity, while composite defects during processing increase the resistivity [27]. In polymeric material, the current flows through crystalline region but non crystalline region allow the current to pass when moisture is present [18]. The phenol formaldehyde is an amorphous polymer and has high volume resistivity. Due to complex structure of lignocellulosic fiber the OH group can absorb the moisture and hence the presence of natural fiber increases the conductivity of the resin.

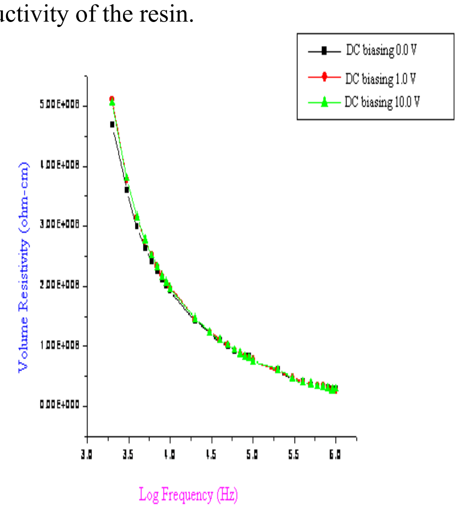

Fig. 3. The volume resistivity of composite material as a function of log frequency at different voltage.

Fig. 4 shows dielectric loss factor as a function of logarithm of frequency for composite material. It is observed that the dielectric loss factor is more at lower frequency and decreases steeply at high voltage (10V) with the increase in frequency. The high value of dielectric loss factor at lower frequency is due to polarization of fiber at lower frequencies.

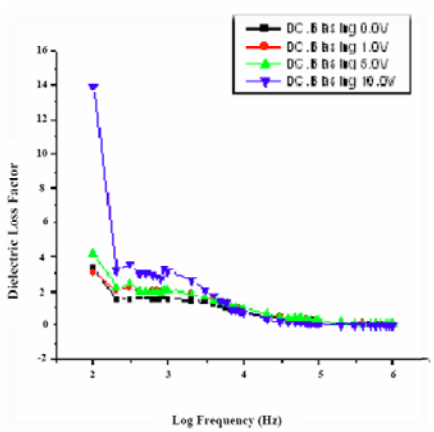

Fig .4. The dielectric loss factor of composite material as a function of log frequency at different voltage.

4. Conclusions

The electrical properties of Hibiscus Sabdariffa fiber composite reinforced with graft copolymer of binary monomers have been studied. The experimental results indicate that the decrease of dielectric constant with increase of frequency is due to orientation polarization. Dielectric dissipation factor increases initially with increase of frequency and decreases with increasing frequency. The volume resistivity of the composite decreases with increase in frequency at different voltages. This is due to the presence of interfacial polarization because of heterogeneity of the system at higher frequency. The dielectric loss factor is decreasing with increase in frequency at various voltages. This is due to polarization of fiber at lower frequencies.

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