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A review on electrical properties of fiber reinforced polymer composites

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ABSTRACT : There has been a growing interest in utilizing natural fibers as reinforcement in polymer composite for making low cost construction materials in recent years. The present paper surveys the research work published in fiber reinforced polymer composite materials with reference to electrical properties such as volume resistivity, dielectric constant, dielectric dissipation factor and dielectric loss factor. Such studies are important because fibrous reinforcements in polymer matrices lead to composite materials with good mechanical properties and electrical properties. The electrical properties such as dielectric constant, dielectric dissipation factor and dielectric loss factor were determined with respect to temperature and frequency. The studies showed that dielectric constant and dielectric dissipation decreased with frequency and increased with temperature, where as the dielectric loss factor decreased with the increase of frequency at fixed temperature and increased with temperature at lower frequencies. It is also observed that the dielectric loss factor decrease with chemical treatment.

Keywords : Natural fiber composites, electrical properties.

INTRODUCTION

In recent years, polymer composites containing natural fibers have obtained considerable attention. The interest in the natural fiber reinforced polymer composite arises rapidly due to the high performance in mechanical properties, significant processing advantages, low cost and low density [1,2]. Natural fibers are renewable, cheaper, pose no health hazards and finally provide a solution to environmental pollution by finding new uses for waste materials. Furthermore, natural fiber reinforced polymer composite form a new class of materials which seem to have good potential in future as a substitute for scarce wood and wood based materials in structural applications. Many plant fibers have found applications as a resource for industrial materials [3,4]. In addition to cellulose, plant fibers contain different natural substances. The most important of these is lignin. The different cells of hard plant fibers are bonded together by lignin, acting as cementing materials. The lignin content of the plant fibers influences its structure, properties and morphology. The composites mainly consist of cellulose fibrils embedded in lignin matrix. These fiber exhibits high electrical resistance. It can be expected that when these fibers are incorporated into low modulus polymer matrix, they would yield materials with better properties suitable for various applications. The properties of natural fiber composites were influenced by fiber loading, dispersion and fiber to matrix adhesion [5-10]. The uses of composites as dielectric are becoming more popular, therefore the electrical properties of natural fiber reinforced polymer composites are very important. The electrical properties such as volume resistivity, dielectric strength of some natural fibers and composites have been studied [7,8].

Fiber reinforced plastics materials not only act as effective insulators, but also provide mechanical support for field carrying conductors. Phenol formaldehyde resin was well known for its electrical insulator characteristics. The incorporation of fiber in polymer matrices is suitable for electrical applications. The composite materials have been used as terminals, connectors, industrials and house hold plugs, switches, printed circuit boards etc. The electrical applications of composite materials have been determined in terms of dielectric constant, volume resistivity and loss factor [11]. The dielectric studies of minerals filled epoxy composite indicate that the electric constant increased with addition of the filler [12]. 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. Electric properties of pineapple reinforced polyethylene composites have been studied by Jayamol *et. al.* [13]. They observed that the increase in the dielectric constant of composite with fiber loading was due to increased orientation and interfacial polarization. The electric properties of sisal fiber reinforced composite showed that the composite has electric anisotropic behavior [14].

The electric 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]. They 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 1to 10^7 Hz. They also noted that dielectric constant decreased with increase of fiber length and frequency. The composite with 1 mm fibers and 30 % fiber content had the highest value of dielectric constant at all frequencies. They also noted the effect of surface treatment on the electric properties of low density polyethylene composite reinforced with short sisal fibers. It have been observed that with alkali, steric acid, peroxide, acetylation and permanganate treatment the dielectric strength of composite materials decreased due to decrease in hydrophilicity of the composite. It has been reported that sisal/ low density polyethylene composites containing 5 % carbon black can be used in antistatic applications to dissipate static charge [19]. 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 [20]. 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 [21]. The dielectric constant decreased with frequency and fiber loading. Treatment with silane, NaOH, latex, heat and acetylation have decreased the dielectric constant value. In hybrid composites the dielectric constant decreased with increase in glass fiber concentration. The volume resistivity of composite decreased with frequency and fiber loading.

Saxena et al. have studied the variation of thermal conductivity and thermal diffusivity of banana fiber reinforced polyester composite caused by addition of glass fiber [22]. They observed that the thermal conductivity of composites increased when compared to matrix. However, the thermal conductivity of the composites with increased percentage of glass fiber decreases in comparison to composite of pure banana fiber. Mai et al. have studied the effect of fiber length and fiber orientation angle on the thermal conductivity of short carbon fiber reinforced composite materials [23]. It is observed that the thermal conductivity of the composite increased with fiber length but decreases with fiber orientation angle with respect to the measured direction.

The polymeric interfaces act as charge carrier generation sites [24]. So it becomes essential to study the effect of interfaces on the change carrier generation, transport and storage in polymeric system.

The physical structure of polymer composites in the solid or viscoelectric state is of great importance in determining the dielectric behavior [25]. The dielectric properties of polymer composite materials have been studied with a view to modify the properties of polymer system for practical applications. The inorganic insulators and dielectrics have been largely replaced by polymers on account of their unique ability for specific needs. Epoxides and polyesters have been used in electronics as insulators, dielectrics substrates, potting compounds, embedding materials and conformal coating [26]. Fiber reinforced composite materials have wide range of applications in aircraft automobile, chemical, medical and electrical industries. In the electrical or electronics industry, these composite materials are used for making panel, switches, and insulators.

Electrical property determination

The capacitance, resistance, dissipation factor and dielectric loss factor have been measured directly by using LCR meter by varying frequencies at room temperature. The square samples of thickness 3mm, length 10 mm and breadth 10 mm have been used for study. The test samples were fixed between two electrodes.

The volume resistivity (ρ) :

It can be calculated from the resistance using following equation,

$$\rho = RA/t$$

where,

A - area of cross-section of the sample

R - resistance

t - thickness of the sample.

The dielectric constant (ε^1) :

It can be calculated from the capacitance using equation

$$\varepsilon^1 = ct/\varepsilon_0 A$$

where,

ε_0 - permittivity of air (8.85×10^{-12} Fm^{-1})

C - capacitance with dielectric

A - area of cross-section of the sample

t - thickness of the sample.

The dielectric dissipation factor (tan δ) :

It can be determined as follow

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

where,

ε^{II} - the dielectric loss.

The dielectric loss factor (ε^{II}) :

It can be determined as follow

$$\varepsilon^{II} = C/C_0\omega$$

where,

C_0 - capacitance without dielectric

ω - angular frequency

DISCUSSION

The resistivity of fiber reinforced composites depend on the moisture content, crystalline and amorphous component present, presence of impurities, chemical composition, cellular structure, microfibrillar angle etc. The shapes of reinforcement determine the interparticle contact, which affect the conductivity of the system. Fibers and flakes having elongated shapes affect the electrical conductivity [27]. The moisture content in fibers increased the conductivity [16]. The hydrophilicity of cellulose fiber is responsible for greater conductivity of the composite. In polymeric materials most of the current flow through the crystalline regions and non crystalline region allows current to pass through it mainly when moisture is present [15]. The hydroxyl groups in the hydrophilic fiber can absorb moisture and hence the presence of the natural fiber increases the conductivity of the resin. It has been found that heat treatment increased the resistivity of the composites as heat treated fiber reinforced composites have lower moisture content than untreated fiber reinforced composites.

It has been observed that dielectric constant increased with increase of temperature and decreased with increase of frequency. This increase in dielectric constant was due to presence of water and impurities present in fiber and also due to mobility of water dipole. When the water content reduced then the value of dielectric constant decreased. The peak height at the transition temperature decreased with increasing frequency. It has been noted that the dielectric constant of 90° orientation sisal epoxy composites is much greater than that of 0° composites. This is due to increased contact surface area of sisal fibers with the electrodes. The orientation of fiber in a composite changes the structure of the total composite, which changes the dielectric constant in different direction [28]. Paul *et. al.* [7] has reported that the change in the fiber loading or treatment changes the structure and hence dielectric constant. They also absorbed that dielectric constant of sisal fiber-low density polyethylene composite increased with increase in fiber loading. The increase is higher at low and medium frequencies and lower at high frequencies, which has been explained by considering the orientation polarization and interfacial polarization. It has been observed that dielectric constant increased with the addition of glass fiber in polyester resin which had higher dielectric constant than base polyester resin, thus resulting in the higher dielectric constant of composites [29]. It has been further observed that dielectric constant decreased with increase of frequency. This was because at high frequencies, the rotational motion of the polar molecules of dielectric is not sufficiently rapid for attain of equilibrium with the field [29]. It was noted that with increase of temperature the dipole becomes free and then response to applied electric field. With a result polarization increased and dielectric constant also increased with temperature [30]. The increase of dielectric constant with temperature is due to greater freedom of movement of dipole molecular chain at high temperature. The dielectric constant of material depends upon the polarizability of the material. If there is greater polarizability of molecule, dielectric constant will be high. The dielectric constant of polymeric materials depends on interfacial, dipole, electronic and atomic polarization [31]. The dielectric constant of lignocellulosic fiber is lower than that of phenol formaldehyde resin [32]. So the incorporation of fibers will decrease the dielectric constant.

In hybrid composites, the dielectric constant decreases with increase in glass fiber content. This was due to hydrophobic nature of glass fiber while banana fiber in hydrophilic [21].

Navin and Deepak have studied the variation of dielectric dissipation factor (tan δ) of sisal fiber epoxy composites at different temperature and frequencies [28]. They observed that dielectric dissipation factor increased with temperature and decreased with frequency.

It has been observed that dielectric loss factor decreased with the increase of frequency at fixed temperature. The 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 [33]. In the composite materials the absorbed moisture at the fiber resin interface acts as a politicizing agent for the polymer, which increases the mobility of the polymer chain and hence brings the loss peak due to temperature glass transition of polyester at higher frequency value [34]. Joseph et al. have observed that in banana fiber composites, at low frequencies, dielectric loss factor increased with increase in fiber loading [21]. They observed that at high frequency, a reverse behavior occurs and the values come closer. This was due to the polarization of the fibers at low frequencies, which was absent at higher frequencies. The dielectric loss factor increased with temperature, particularly at lower frequencies at which dielectric loss due to chain motion of polymer is more effective due to glass transition temperature of the polymer. At higher frequencies, the dielectric loss factor is low and remained more or less constant with increasing temperature because the orientation polarization due to chain motion of polymer can not keep phase with the rapidly oscillating electric field [35].

CONCLUSION

The electric properties of natural fiber reinforced composites were reviewed. The electrical properties of natural fiber reinforced polymer composites are very important. Due to their unique the inorganic insulators and dielectrics have been replaced by polymers for specific needs. Epoxides and polyesters have been used in electronics as insulators, dielectrics substrates, potting compounds, embedding materials and conformal coating. The moisture content in fibers increases conductivity of the composites. . It has been found that heat treatment increased the resistivity of the composites as heat treated fiber reinforced composites. The increase of dielectric constant with temperature is due to greater freedom of movement of dipole molecular chain at high temperature. It has been observed that dielectric dissipation factor increased with temperature and decreased with frequency. It has been further observed that dielectric loss decreased with the increase of frequency at fixed temperature. It can be concluded that with systematic and persistent research there will be good scope and better future for polymer reinforced composites for suitable electrical applications such as terminals, connectors, switches, circuit boards etc.

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