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Dielectric and Thermal Properties of Carrot Fibers –Epoxy Composites

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Abstract

Epoxy composites were prepared with two sizes of carrot fibers in different weight percent (10%, 20%, 30% and 40%) by hand lay-up technique. The dielectric constant and dissipation factor (tanδ) of pure epoxy resin and composites were measured in a frequency range of 50 Hz to 5 MHz with increase fibers content, dielectric strength (breakdown voltage) and thermal conductivity were evaluated as a function of fiber content. The dielectric constant and dissipation factor values were found to be higher for fiber reinforced system than the pure epoxy. The dielectric strength values decreases and the values of thermal conductivity increases with fibers content.

Keywords: natural fiber, composites, dielectric and thermal properties.

خصائص العزل الكهربائي والحراري لمتراكبات الياف الجزر–ايبوكسي

الخلاصة

تم تحضير متراكبات الايبوكسي باستخدام حجمين من الياف الجزر بنسب وزنية مختلفة (10%, 20%, 30% و40%) بتقنية الطريقة اليدوية. تم حساب ثابت العزل الكهربائي ومعامل الفقدان العزلي لنمادج راتنج الايبوكسي والمتراكبات لمدى من الترددات Hz(50- 5000000) مع زيادة محتوى الالياف وكذلك تم حساب متانة العزل الكهربائي (فولتية الانهيار) والتوصيلية الحرارية كدالة مع نسب الالياف. ان ثابت العزل الكهربائي ومعامل الفقدان العزلي للمتراكبات كانت بقيم اعلى من الايبوكسي لوحده. تناقصت قيم متانة العزل الكهربائي و زادت قيم التوصيلية الحرارية مع زيادة محتوى الالياف.

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Introduction

Over the past two decades, plant fibers have been receiving considerable attention in the automotive, packaging, and construction industries as substitutes for synthetic fiber reinforcements. Unlike the traditional synthetic fibers these lignocellulosic fibers are able to impart certain benefits to the composites such as low density, high stiffness, low cost, renewability, biodegradability and high degree of flexibility during processing [1].

In recent years, natural fiber composites proved of interest for dielectric applications, showing also some potential for future application as dielectric materials in microchips, parts of transformers, and circuit boards [2, 3]. The study of electrical properties of natural fiber reinforced polymer also indicates their suitability as insulating materials for special applications such as suspension insulators, bushing, studs, sleeves, gaskets, spacer panels and switch boards [4, 5].

Alongside the emergence of natural fibers there has also been a growing interest in electrically conductive polymer composites. A great deal of work has been performed to make polymers conductive by incorporating conductive fillers. For a given polymer type the electrical properties is determined by the amount and type of conductive additives. The electrical properties increase significantly with increasing water content and ions or ionic sites. Such electrically conductive composite materials are widely being used in the areas of electrostatic discharge dissipation, electro-magnetic interference shielding and various other electronic applications [3, 6, 7].

Epoxy and epoxy based composites are preferred insulating materials for several electrical applications, especially printed circuit boards, bushings, generator groundwall insulation system and cast resin transformers [8].

The dielectric constant of a material depends upon the polarizability of the molecules. The polarizability of nonpolar molecules arises from electronic polarization (in which the application of applied electric filed causes a displacement of the electrons relative to the nucleus) and atomic polarization (in which the application of applied electric filed causes a displacement of the atomic nuclei relative to one another). In the case of polar molecules a third factor also comes into play which is orientation polarization (in which the application of applied electric filed causes an orientation of dipoles) [3].

Dissipation factor or loss tangent is defined as the ratio of the electrical power dissipated in a material to the total power circulating in the circuit. The measurements of dissipation factor of an insulating material are important, since the loss tangent is a measure of the electrical energy that is converted to heat in an insulator [3].

The dielectric properties of natural fibers- polymer composites such as banana, jute, sisal, coir, pineapple, waste paper, oil palm, flax fibers were investigated [5, 9-14].

Even though, a very large quantity of work has been published on various natural fibers and its

composites, an effort has been made in the present work to introduce a new natural fiber i.e. carrot as reinforcement in the development of new composite materials for lightweight structures.

The carrot is abundantly available and renewable in nature. This economical source encourages us to utilize carrot. The overall objective of this work is to use two fiber sizes and incorporating them into epoxy resin matrix to prepare the composites at various weight percentages of fibers. The resulting composites were tested and characterized to evaluate dielectric constant, dissipation factors, dielectric strength, and thermal conductivity.

Experimental

Materials

Epoxy resin group type Quickmast 105 (DCP) was used. Specific gravity and viscosity of the epoxy resin were 1.04 and 1 poise respectively at 35°C. The ratio between resin and hardener for this study was 3:1 by weight.

Filler: Carrot seeds were purchased locally from vegetable supplier. They were cleaned to remove all foreign matter such as dust, dirt, and stones. The juice was removed from carrot seeds the solid waste from carrot juice is rich in fiber which regarded as a functional fiber source. The waste was dried to a constant weight and then grounded by using a grinder and sieved. Two sizes were obtained. Once (fine fiber) is less than 50 µm and the other (coarse fiber) is between 100-150 µm which represent as accumulated fibers.

Processing of composites

To prepare the composite samples, a mould of size (100×100×3 mm) was made from glass. Silicon was used for joining frames. Then plastic sheet was placed in the bottom of the mould. The composites were prepared with hand lay-up technique. The carrot fiber-epoxy composites were prepared with 10, 20, 30, and 40 wt. % fiber content for both sizes.

Initially epoxy resin and hardener were mixed together based on the weight ratio to form a matrix. Then some of the weighted fibers were added to epoxy resin with continuous mixing. This process was continued until weighted materials were finished. Then the mixture was poured into the mold. Then it was covered by plastic sheet. The curing time was around 24 h at room temperature (23 °C). The composite was taken out of the mould in the form of a plate and was cut and machined to produce samples of size 20×20×2 mm conforming for electrical properties and 40 mm diameter disk for thermal conductivity testing. All these tests were carried out for pure epoxy, and carrot fiber reinforced epoxy composites of different loading for the both sizes.

Electrical properties

Dielectric constant and Dissipation factor

The dielectric constant έ of a material is defined as the ratio of the capacitance of a condenser containing the material to that of the same condenser under vacuum [3].

Dielectric constant (έ) can be calculated from the capacitance using the equation:

$$e' = \frac{Ct}{e_o A} \qquad \text{……..(1)}$$

Where C- capacitance of the material
t- thickness of the sample
- permittivity (8.85×10^{-12} Fm^{-1})
A- area of sample under electrode.

Dissipation factor or loss tangent (tanδ) is a measure of the power dissipated. It can be calculated from the equation:

$$\tan d = \frac{e''}{e'} \qquad \text{..... (2)}$$

Where □ □ is the loss factor and έ is the dielectric constant [3].

Dielectric constant and dissipation factor were estimated according to Agilent 4294A PRECISION IMPEDANCE at frequencies range (5-5000000) Hz.

Dielectric Strength

The dielectric strength measurements in the present study are performed using a breakdown test cell BAUR (0-60) KV designed with the appropriate electrodes and the breakdown tests are carried out in a medium of transformer oil.

The breakdown voltages V (KV) of the samples are recorded and the dielectric strength, E (KV/mm) can be obtained from the following equation [15]:

$$E = \frac{V}{t} \qquad \text{..... (3)}$$

Where: t is the thickness of the sample in millimeters.

Thermal conductivity

Lee's disc instrument is used to calculate thermal conductivity of the samples under test. The heat that flows through across sectional area of the sample per unit time (e) (W/ m^2.K) is calculated from the following equation [16]:-

$$IV = pr^2 e(T_A + T_B) + 2pre\left[d_A T_A + d_S \frac{1}{2}(T_A + T_B) + d_B T_B + d_C T_C\right] \qquad \text{..... (4)}$$

Where
I is the current value through the heater.
V is the potential difference across the heater.
r is the radius of disc.
T_A, T_B and T_C are the temperature of the brass discs A, B and C respectively. d_A, d_B and d_C are the thickness of the brass discs A, B and C respectively.
d_S is the thickness of the sample.
The values of thermal conductivity K (W/m.K) are calculated by applying the equations:-

$$K\left(\frac{T_B - T_A}{d_S}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \frac{1}{4}d_s\right)T_A + \frac{1}{2r}d_S T_B\right] \qquad \text{..... (5)}$$

Results

Dielectric constant

Figures 1 and 2 present the effect of fiber content and fiber sizes on the dielectric constant values of composites. It can be seen that dielectric constant increases with fiber content at all frequencies. The minimum dielectric constant is exhibited by the pure epoxy and maximum by composite containing 40 wt% of fiber. This is because of the fact that epoxy is a non-polar material and has only instantaneous atomic and electronic polarization to account [3]. The dielectric constant increased with

fiber content. This is attributed to the increase in orientation polarization of the polar groups present in lignocelluloseic fibers [2, 17].

The dielectric constant values decrease with increase in frequency for all the composites. The decrease in dielectric constant with frequency is due to decrease in orientation polarization at high frequencies. At low frequencies, complete orientation of the molecule is possible while at medium frequencies there is only little time for orientation. Orientation of the molecules is not possible at all at very high frequencies [3].

Dissipation factor

The dissipation factor of fine and coarse carrot fibers composites samples at different fiber content are presented in Figs. 3 and 4. It can be seen that the dissipation factor increased with fiber loading. This is because the presence of carrot fiber facilitated more storage of electric current due to the presence of polar functional groups in the composites [2]. Where fiber content increases, the polar groups that is present also increases which leads to an increment in orientation polarization. This causes dissipation factor to increase [3, 17].

It can be observed that for all fiber contents, there is a decrease in the dissipation factor values with increasing frequency. The decrement with frequency is due to decease in orientation polarization at high frequencies [3].

Dielectric Strength

The effect of fiber content on dielectric strength of both sizes samples is shown in Fig. (5). It is observed that the dielectric strength decreases with increase in fiber content in composites.

From the figure it can be seen that the dielectric strength values of the carrot fiber composites are lower than that of the pure epoxy. This implies that the conductivity increased upon addition of lignocellulosic fibers. This is due to the presence of polar groups, which facilitate the flow of current between the electrodes which causes lower breakdown voltage [18].

It can also be seen that the coarse fiber composites display low dielectric strength values when compared to fine fiber composites. This is due to the different distribution of the fibers in the composites, a uniform distribution were achieved in fine fibers, while in the case of coarse fibers there were agglomerations in the composites which lead to increase of polar groups in the area [8].

Thermal conductivity

The thermal conductivity of fine and coarse carrot fibers composites samples at different fiber content are presented in Fig. 6. In case of fine fiber composites there are a little increase in thermal conductivity value at 10 wt% and no changes in the values at the other weight percents. While in case of coarse fiber composites there is a relatively small increase in the thermal conductivity values with fibers content. This is due to the increase of phonons numbers in the material [19].

Conclusions

The results indicate that the carrot fiber epoxy composites are electrical and thermal insulators. Fine carrot fiber composites indicate higher

electrical and thermal insulating than coarse carrot fiber composites.

The dissipation factor was seen to increase with fiber content which indicates that the electrical charges can be retained over a longer period of time.

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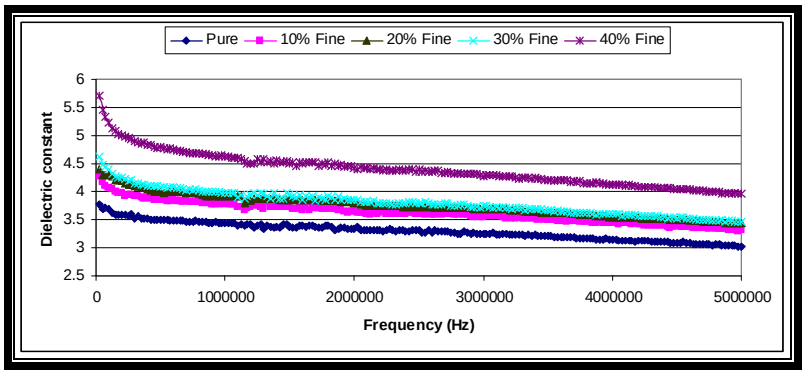

Figure (1): Variation of dielectric constant with frequency of fine fiber content

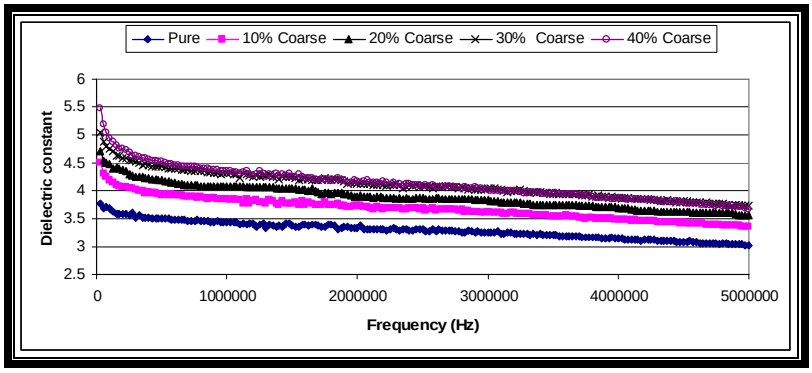

Figure (2): Variation of dielectric constant with frequency of coarse fiber content

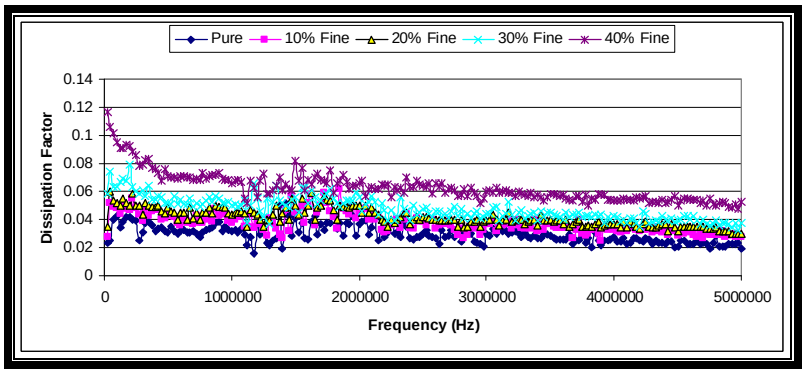

Figure (3): Variation of dissipation factor with frequency of fine carrot composites.

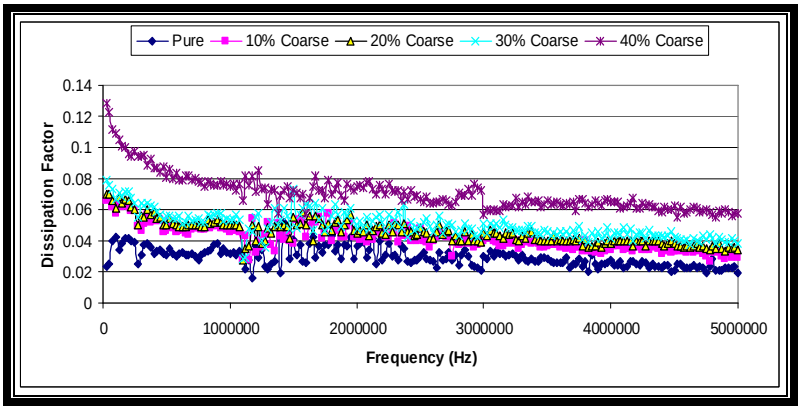

Figure (4): Variation of dissipation factor with frequency of coarse carrot composites.

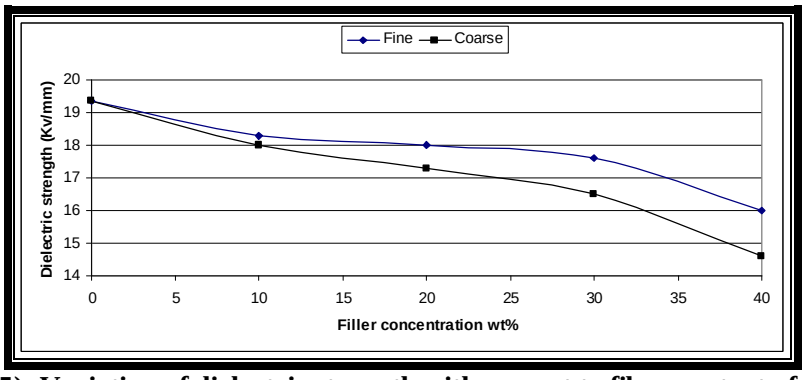

Figure (5): Variation of dielectric strength with respect to fiber content of fine and coarse carrot fiber composites

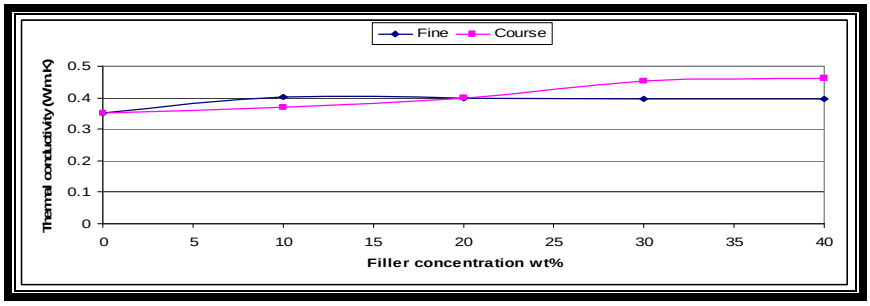

Figure6: Variation of thermal conductivity with respect to fiber content of fine and coarse carrot fiber composites