Effect of fiber content on the thermal conductivity and dielectric constant of hair fiber reinforced epoxy composite

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Abstract. This paper reports on the dielectric and thermal properties of hair fibers reinforced epoxy composites. Hair is an important part of human body which also offers protection to the human body. It is also viewed as a biological waste which is responsible for creating environmental pollution due to its low decomposition rate. But at the same time it has unique microstructural, mechanical and thermal properties. In the present work, epoxy composites are made by solution casting method with different proportions of short hair fiber (SHF). Effects of fiber content on the thermal conductivity and dielectric constant of epoxy resin are studied. Thermal conductivities of the composites are obtained using a Unitherm™ Model 2022 tester. An HIOKI-3532-50 Hi Tester Elsier Analyzer is used for measuring the capacitance of the epoxy-SHF composite, from which dielectric constant ($\varepsilon_r$) of the composite are calculated. A reduction in thermal conductivity of the composite is noticed with the increase in wt. % of fiber. The dielectric constant value of the composites also found to be significantly affected by the fiber content.

Key words: Hair fiber, dielectric constant, thermal conductivity, biological waste

1. Introduction
Polymer matrix composites are commonly used in microelectronic application due to their easy fabrication, light weight, low cost and excellent insulation properties. The dielectric constant of a material plays an important role in functioning of the electronic equipment. Dielectric behaviour of polymer composite filled with different inorganic fillers has been reported by many researchers. Mishra et al. [1] studied the dielectric behaviour of epoxy composite with solid glass microsphere (SGM) as the filler material and observed that increase in filler content have significant effect on the dielectric constant of the composite. Agrawal et al. [2] investigated the mechanical, dielectric and thermal properties of polypropylene composite filled with AlN and SGM. Mishra et al. [3] have also studied the dielectric properties of hybrid composite filled with SGM and boron nitride.

Use of natural fibers as a reinforcing material in polymer matrix composite has been growing rapidly due to their good mechanical, tribological, dielectric and insulating properties. These fibers are also biodegradable in nature having low cost and low toxicity. In electrical and electronics application natural fiber reinforced polymer composite can also be a better substitute to synthetic fiber due to their better electrical insulating properties. Dielectric behaviour of polymer composite reinforced with different natural fiber has been researched by many researchers. Mishra et al. [4] investigated the
dielectric properties of epoxy composite reinforced with chicken feathers. Joseph et al. [5] investigated the electrical properties of phenol formaldehyde composite reinforced with banana fiber with different fiber loading and chemical treatments. Elammaran et al. [6] investigated the dielectric properties of epoxy matrix composite reinforced with pineapple leaf fiber. Nayak et al. [7] reviewed the electrical insulating properties of polymer composite reinforced with natural fibers. A lot of work has been reported on dielectric behaviour of polymer composite reinforced with different natural fibers. But thermal and dielectric property of hair fiber reinforced epoxy composite has not been researched. So in the present work effect of fiber content on thermal conductivity and dielectric constant of hair fiber reinforced epoxy composite has been investigated.

2. Experimental Details

2.1. Composite Fabrication
Composite samples in the present study are fabricated by solution casting method. Raw hair fiber is collected from a saloon, washed with detergent and pure water. After washing, these fibers are kept in sunlight for few hours to remove the moisture content. After that with the help of a scissor these hair fibers are cut into 3-4mm length approximately. The epoxy resin (LY556) is mixed with its corresponding hardener (HY 951) in the ratio of 10:1 by weight and then short hair fiber is added into it with different weight proportions to prepare the composites. The mixture was mixed properly and then decanted into to a cylindrical mold of 1 cm diameter and 10 cm depth and also to a mold of size 5 cm diameter and 0.3 cm thickness. The casting is left as it is for 24 hours to cure at room temperature.

2.2. Thermal Conductivity Test
Unitherm™ Model 2022 tester is used to compute the thermal conductivity of the epoxy-SHF composite. To conduct the test circular specimen of size 50mm diameter and 3mm thickness with both sides having flat surface are used. ASTM E-1530 standard is followed to perform the test.

2.3. Dielectric Test
The dielectric constant which is also known as the relative permittivity of a substance is the measure of permittivity of the substance relative to permittivity of vacuum. In the present research work dielectric constant of epoxy-SHF composite is measured in a HIOKI-3532-50 Hi Tester Elsier Analyzer. To conduct the test disc shaped composite specimen of 10mm diameter and 2-3 mm thickness are prepared. Both upper and lower surface of the test specimen are coated with silver paste. During the test 500mv AC voltages is applied and in a frequency range of 100Hz to 1 MHz dielectric constant of the composite samples are measured. The following formula can be used to compute the dielectric constant of the composite specimen

$$D_k = \frac{Ct}{\varepsilon_0 A}$$

where C represents the capacitance of test specimen, t represents the thickness of the disc, $\varepsilon_0$ is the dielectric constant of vacuum and A is the disc area.

3. Results and Discussion

3.1. Thermal Conductivity Test
The experimental thermal conductivity values of hair fiber reinforced composites with different proportions of SHF are shown in the Table.1. Theoretical values obtained by using rule of mixture [8] are also presented in this table for comparison. Fig.1. Compares the theoretically obtained effective thermal conductivity values of the composites with those obtained from experiments. It can be seen that the percentage error associated with each comparison is not very high. It is further noted that with the increase in fiber content, the effective thermal conductivity of the composite decreases which is attributed to the low intrinsic thermal conductivity of hair fiber.
### Table 1. Thermal Conductivity of Epoxy-SHF Composites

| SHF content (wt%) | Theoretical Thermal conductivity (W/mK) | Experimental Thermal Conductivity (W/mK) | Error (%) |
|-------------------|-----------------------------------------|------------------------------------------|-----------|
| 0                 | 0.363                                   | 0.363                                    | 0         |
| 2                 | 0.359                                   | 0.342                                    | 4.7       |
| 4                 | 0.355                                   | 0.335                                    | 5.6       |
| 6                 | 0.351                                   | 0.327                                    | 6.8       |

![Graph showing thermal conductivity of composite at different wt. % of SHF]

**Fig 1.** Thermal conductivity of composite at different wt. % of SHF

#### 3.2. Dielectric Test

The dielectric constants of epoxy-SHF composites at room temperature with different wt. % of SHF content and at different frequencies (100Hz - 10^6 Hz) are presented in the Table 2. The variation of dielectric constant of the composite as a function of hair fiber content at different frequencies is shown in Fig. 2. It is observed that dielectric constant of the composite decreases with increasing fiber content and frequency. The reduction in dielectric constant with increasing frequency is the expected behaviour in most of the dielectric materials.

### Table 2. Dielectric Constant of Epoxy-SHF Composites

| Frequency (Hz) | Weight % |
|----------------|----------|
|                | 0        | 2        | 4        | 6        |
| 10^2           | 4.7      | 4.30     | 4.15     | 4.05     |
| 10^3           | 4.4      | 4.10     | 3.97     | 3.87     |
| 10^4           | 4.2      | 3.95     | 3.83     | 3.78     |
| 10^5           | 4.0      | 3.85     | 3.73     | 3.68     |
| 10^6           | 3.9      | 3.80     | 3.65     | 3.55     |
4. Conclusions
This study reveals that the reinforcement of short hair fiber leads to substantial reduction in the effective thermal conductivity of epoxy composites and thereby improves their insulation capabilities. It is seen that addition of 6 wt. % of fiber results in 9.91 % reduction in the conductivity of epoxy. It also shows that the dielectric constant of the composites also varies with the fiber content and the operating frequency.

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Fig 2. Dielectric constant of composite at different wt. % of SHF