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Development of Hybrid Cellulosic-Keratineous Fibers Base Epoxy Composites for Automobile Applications

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ABSTRACT

The development of hybrid cellulosic-keratinous fibers reinforced epoxy composites was investigated in this study. Hybrid composites were fabricated by mixing coir fiber (CF) and chicken feather fiber (CFF) with the epoxy matrix in a randomly dispersed approach. The mechanical properties such as tensile, flexural and hardness properties were determined. Also, wear property, thermal conductivity and moisture absorption potentials of the developed composites were studied while the surface morphology of the composite fracture surface was examined using scanning electron microscopy (SEM). The results revealed that all the selected properties were improved compared to the unreinforced epoxy matrix. Sample with 1% CF and 2% CFF gave the optimum results and the combination of good mechanical, wear, thermal insulating and moisture resistance properties. It was discovered that higher volume of CFF in synergy with low volume of CF was responsible for performance. The results revealed that the materials can be used in automobile due to the inclusion of light-weight bio-fibers that gave good insulating properties in epoxy composites in conjunction with good mechanical, wear and moisture resistance.

Key words: *Bio-fiber; ecofriendly materials; green composites; agro-wastes; pollution control*

1. INTRODUCTION

Polymers composites are lightweight materials with unique properties that can be tailored for various purposes like domestic, industrial and structural applications. However, the continuous large-scale production of polymer composites has been threatened due to its non-biodegradable nature as it constitutes environmental pollution after service life. Thus, recent researches, taking environmental impact as primary factor, are aimed at producing green composite- biodegradable polymer composites. In view of this, renewable and eco-friendly natural fibers have been employed in reinforcing polymer matrix.

Natural fiber reinforced composites possess low density, high specific strength, low cost and is readily available with ease processability [1, 2]. They are obtained from plants, animals or minerals. Plant are rich in cellulose which enhances tensile and flexural strength while animal fibers are keratinous and hydrophobic enabling them to blend easily with polymer matrix. These inherent properties of natural fibers coupled with their potential of providing an economically viable and feasible means of converting agricultural waste into useful resources for materials development have drawn research interest.

Natural fibers can be added to polymer matrix in their untreated state. However, for better property optimization and to improve the interfacial bonding between hydrophilic natural fibers and hydrophobic polymer matrix, fiber pretreatment is recommended [3]. Chemically, fiber pretreatment helps reducing the hydrophilicity of the fiber while physically removing waxy materials covering the fiber surface, thereby changing the fiber texture [4]. Kumar et al. [5] studied the effect of treated coir fiber (CF) on epoxy polymer composite and reported an increase in tensile and impact strength with the addition of treated CF. Obele and Ishidi [6] treated CF and used for the fabrication of helmet shell using epoxy resin as matrix. The tensile

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modulus and impact energy of the helmet shell was enhanced. Okoro et al. [7] synthesized and examined the mechanical properties of high-density polyethylene reinforced with chicken feather fiber (CFF) treated with alkaline. The tensile and flexural strength of the developed composites were improved.

Single fiber reinforcement only enhances a particular property and has limitation in offering a range of property enhancement. Thus, in bid to boost the mechanical robustness and increase the functionality of polymer composites by harnessing the inherent unique properties of two or more different fibers, hybridization is being considered [8]. Plant/plant and plant/animal fiber reinforced hybrid composite have been studied [9-11]. Khanam et al. [12] utilized equal weight ratio but different fiber length of treated coir and silk to reinforce polyester composites. Improvements in the mechanical properties with the maximum performance observed in polyester composite with 2 cm were reported. Alagarsamy et al. [13] used coconut coir and chicken feather to develop hybrid composite and reported improvement in tensile and flexural properties of the hybrid polyester composites. Tusnim et al. [14] also reported increase in mechanical properties of polypropylene hybrid composite reinforced with jute and sheep wool. Breakthroughs in hybrid polymer composites offer the opportunity to exploit the desired properties of different fibers while minimizing individual drawback.

In this work, CFF and CF were selected for the research. The research seeks to harness the improved interfacial adhesion of CFF with polymer matrix and enhanced stiffness of cellulose CF in developing a hybrid epoxy composite. The microstructure of the fracture surface of single and hybrid reinforced epoxy composites were examined. The mechanical, thermal properties, wear behaviour, water absorption properties of the hybrid composites were as also evaluated. The material is expected to be used in the production of electrical components of the automobile where presently, polymers like polypropylene, polyamide, polyvinylchloride and polyethylene are being used. However, epoxy is the most suitable polymer for electrical application and it has been widely used for many electrical applications in particular as an insulating material [15]. Therefore, this also needs to be introduced in automobile parts.

2. MATERIALS AND METHODS

Coconut husk fibers and chicken white feathers were locally sourced from Akure, Nigeria. While, epoxy resin, hardener, and sodium hydroxide were procured from Pascal Scientific.

2.1 Extraction of CFF

White chicken feather was gathered, washed and sun dried for 5 days. After drying, the feathers were cut to about 20 mm and used in same condition.

2.2 Extraction and chemical modification of the CF

Coconut fibers were chopped and treated in a water bath shaker with sodium hydroxide at 50°C and maintained for 1 hour before removal. It is then rinsed with distilled water until pH 7 was reached, before drying.

2.3 Composite fabrication

Epoxy resin was used as matrix for all samples. The epoxy resin was mixed with hardener in ratio 2:1 and, CF and CFF of predetermined weight percent as shown in Table 1. The fibers were mixed in different proportions in a container and stirred thoroughly till the fibers were evenly distributed in the epoxy matrix. The homogenous mixture was poured into the mould and allowed to set. The composites were carefully removed and allowed to post cure in air at room temperature.

Table 1 - Formulation of Composites Samples

Sample	*Epoxy_Resin (%)*	*Coconut_Fiber (%)*	*Chicken_Fiber (%)*
A (control)	100	-	-
B	97	3.0	-
C	97	2.5	0.5
D	97	2.0	1.0
E	97	1.5	1.5
F	97	1.0	2.0
G	97	0.5	2.5
H	97	-	3.0

2.4 Mechanical Properties Test

Tensile properties of the composites were evaluated in accordance with ASTM D3039/D3039M-17 [16]. The test was carried out on three samples from each composition and the average value was computed as used in this work.

Flexural test was carried out using a 3-point bending test platform. It was performed in accordance with the ASTM D790-03 [17]. The data gotten from the test was used to determine the flexural properties.

Hardness test was conducted on the specimen using a Shore D hardness tester in accordance with ASTM D2240-00 [18]. The hardness test was carried out using Shore D hardness tester. This measures the depth of an indentation by a given force on a presser foot in a consistent manner

2.5 Thermal Conductivity

Thermal test was carried out using the Lee's disk apparatus to determine the thermal conductivity of the developed composite in accordance with ASTM E1530-19 [19]. Lee's disk apparatus was used for measuring the thermal properties of the developed composites and the control sample. The process includes placing the sample in between the disks while temperature controller was activated to a preset temperature value (t). Heat flows via the first disk through the sample to the other disk. The two sensors connected to the disks were used to sense temperature changes in the metal disks. Temperature change in the other disk was noted and recorded at a regular interval until there was no temperature change taking place. The thermal conductivity was evaluated using Eq.1.

$$\mathbf{k = mcp(\theta 1 - \theta 2)4x/\pi D2(T1 - T2)\ t\ (W/mK)}$$
(1)

where,

m - mass of the disk, 0.0078 Kg
cp - specific heat capacity of the disk, 0.91 kJ/ KgK
θ_1, θ_2 - initial and final temperature of disk B
D - diameter of the sample, 0.04 m
x - thickness of the sample, 0.003 m
T_1, T_2 - temperature of disk A and B in Kelvin
t - final time taken to reach a steady temperature

2.6 Water Absorption Test

Water absorption tests were carried out in accordance with ASTM D5229M-12 [20]. The samples were weighed in air before and after immersion in water. To avoid error in the measurement, wet samples were cleaned before weighing. The weight measurement was taken periodically at time intervals of 24 hours for 168 hours until water saturation was noticed for the composites. The average percentage of water absorbed by the composite was determined using Eq.2.

$$W\,(\%) = \frac{Wt - W0}{Wo} X\,100 \qquad (2)$$

Where W is percent water absorption, Wo and Wt are the dry weight, and the weight of the specimen after time t respectively.

2.7 Morphology analysis (Scanning Electron Microscope analysis)

SEM was used to examine the surface morphology of the treated and untreated composites and the control sample. Certain portion from the fractured surface was cut and coated with gold before examining on a PhenomProX scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) operated at 15 KV.

3. RESULTS AND DISCUSSION

3.1 Flexural strength

Flexural strength represents the highest stress experienced within the material at the time of rupture. The variations of the flexural strength at peak for fiber reinforced composites are shown in Fig. 1. It was revealed that sample F with 1 wt% CF and 2 wt% CFF possessed the highest flexural strength of 8.96 MPa which is about 54.2% improvement over the unreinforced sample. The improvement is due to good adhesion between CF and CFF with the epoxy matrix.

3.2 Flexural modulus

Flexural modulus of composite samples is presented in the Fig. 2. It can be observed that the flexural modulus tends to increase with the fiber addition. This is significant with the sample B, C, D, E and F. A drastic decrease in the modulus was observed for sample G and H. The decrease in the flexural modulus is due to improper blending and interaction between the constituent at this composition. Sample F (1 wt% CF and 2 wt% CFF) has the highest flexural modulus value of 9 GPa. Comparing single reinforced epoxy composite B and H with 3 wt% of CF and CFF respectively, the modulus of sample B was higher than that of sample H due to the high strength of coir.

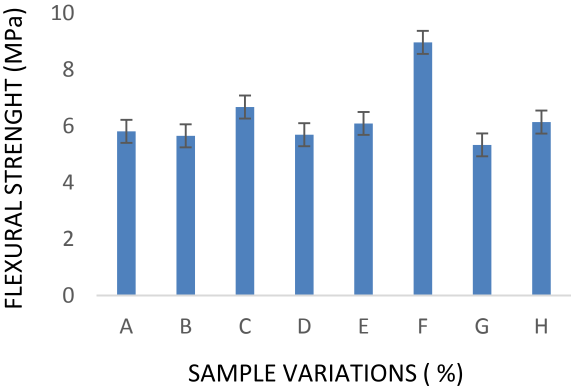

Fig.1 *Flexural strength of hybrid coir fiber/chicken feather fiber reinforced epoxy composites and the control*

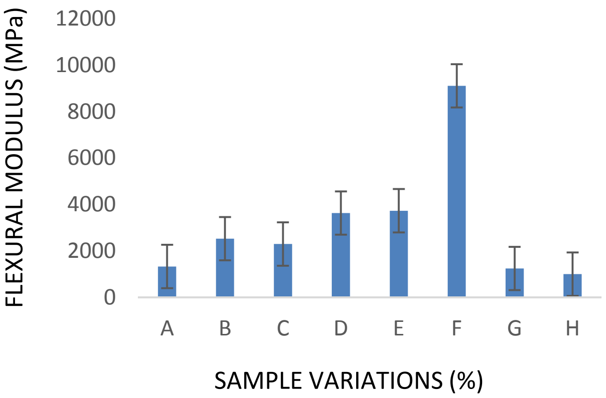

Fig. 2 *Flexural modulus of hybrid coir fiber/chicken feather fiber reinforced epoxy composites and the control*

3.3 Tensile modulus

Fig. 3 shows the tensile modulus of the single and hybrid composites. Improvement in the tensile modulus of the reinforced composites over the neat sample was observed. This can be attributed to the presence of high strength fibers and their strong bonding with the epoxy matrix. The superior tensile modulus was obtained from sample F (1 wt% CF and 2 wt% CFF) with 1.4 GPa. It was also noticed that the hybrid composite has higher tensile modulus than the single reinforced composites (sample B and H).

3.4 Tensile Strength

Fig. 4 shows tensile strength of the single and hybrid fiber reinforced composites. From the results, all the reinforced samples are observed to have better tensile strength than the neat sample. The enhancement in tensile strength can be attributed to good adhesion between the stiff fibers and the soft epoxy matrix. Like, the high strength fibers were well dispersed in the epoxy matrix, thereby ensuring proper load transfer from the matrix to the reinforcement. The highest tensile strength of 43.09 MPa was observed in sample F with 1 wt% CF and 2 wt% CFF.

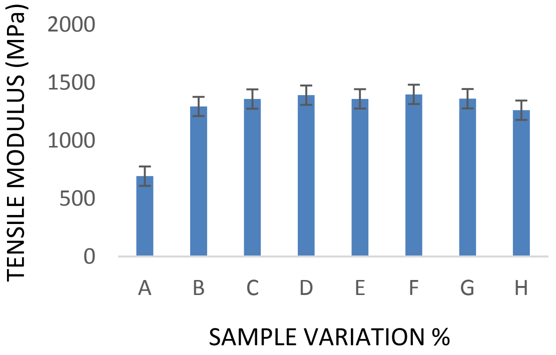

Fig. 3 *Tensile modulus of hybrid coir fiber/chicken feather fiber reinforced epoxy composites and the control*

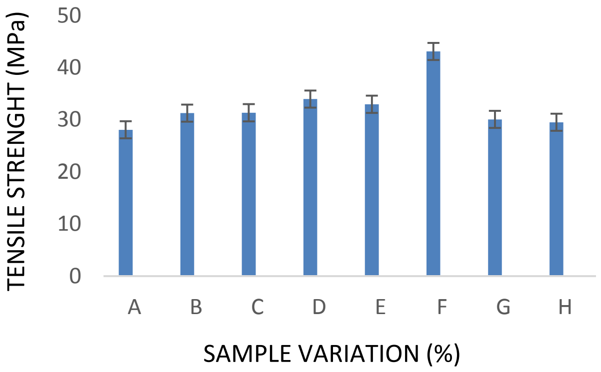

Fig. 4 *Ultimate tensile strength of hybrid coir fiber/chicken feather fiber reinforced epoxy composites and the control.*

3.5 Hardness Test

Fig. 5 shows the hardness values of the developed composite samples. It was noticed that all the developed composites have better hardness value than the control with the hybrid performing better than the single reinforced composites. Comparing the hardness value of the single reinforced fiber, the CF reinforced composites possess better hardness than the CFF reinforced composites. Composite sample F with 1 wt % CF and 2wt % CFF exhibits highest hardness with about 45.7% increment over the unreinforced sample. The enhancement is due to uniform dispersion of fiber within the matrix and good interfacial adhesion between the fibers and the matrix.

3.6 Thermal conductivity test

Fig. 6 shows the variation in thermal conductivity of the developed composites and the control sample. It was observed that there was significant decrease in the thermal conductivities of the developed composites when compared with the control sample with value 1.83 W/mk. Sample F exhibiting the lowest thermal conductivity with a value of 0.03 W/mk was achieved. The significant reduction in thermal conductivity can be attributed to the interfacial resistance (Kapitza resistance) offered by the fibers to phonon movement within the matrix. This can be attributed to honeycomb structure of CFF which reduces solid conduction, thereby enhancing the insulating properties of the composite. Despite high cohesiveness, superior dielectric property, small shrinkage, good chemical stability and easy processing of epoxy based composites [21], conventional epoxy based materials fail for electrical insulation application in ultra-high voltage direct current transmission such as gas-insulated metal-enclosed transmission line (GIL) or gas-insulated metalenclosed switchgear (GIS). Recently, much research focuses on polymer nanocomposite applications in electrical insulation, and the incorporation of nanoparticles demonstrates combined progressive electrical, mechanical and thermal improvements over conventional microfiller systems [15]. Various researches are on-going to improve insulating properties of epoxy, hence, the results of this research is in line with the interest of researchers. These composites can be considered for such applications where previous products are failing.

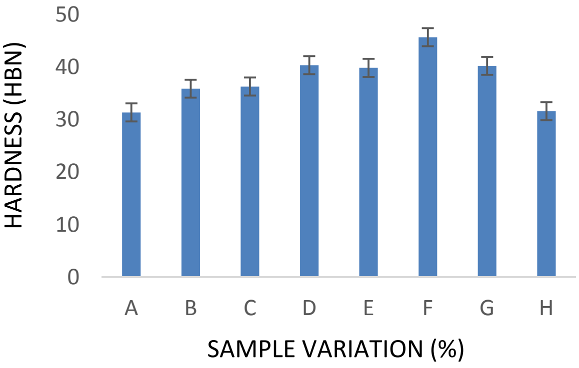

Fig. 5 *Hardness values of hybrid coir fiber and chicken feather fiber reinforced epoxy composites*

3.7 Wear test

Fig. 7 shows the wear index of the developed composites. It can be observed that the single reinforced composite samples B and H has the lower wear index compared to the other composite samples. Sample B with 3 wt% of CF possess the least value (0.046 mg) which implies better resistance to abrasion. It was also noticed that as the CF decrease, the wear index increases from sample C through F before experiencing another decrease in G. This shows that CF has better wear resistance than CFF.

3.8 Water Absorption Test

Fig. 8 shows the variation of percentage of water absorbed by the composite samples. Here, the nature of the reinforced fiber is primarily responsible for the water absorption behaviour. It can be observed that composite with higher wt% of CF absorbed more water than those with higher CFF. The increase in affinity for water is due to the hydrophilic nature of cellulose CF. Similarly, the decrease amount of water absorbed by composites with higher wt% of CFF is as a result of hydrophobic nature of keratinous CFF. Thus, for applications prone to wet environment, higher CFF can be recommended.

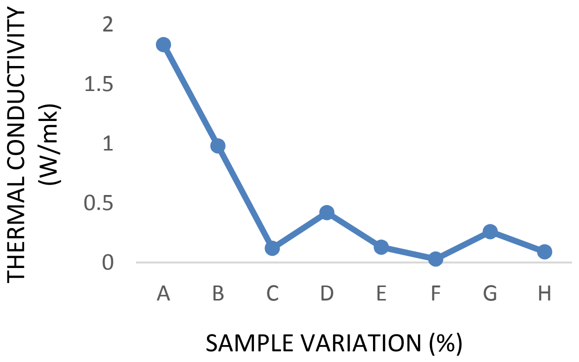

Fig.6 *Thermal conductivities of hybrid coir fiber/chicken feather fiber reinforced epoxy composites in several samples.*

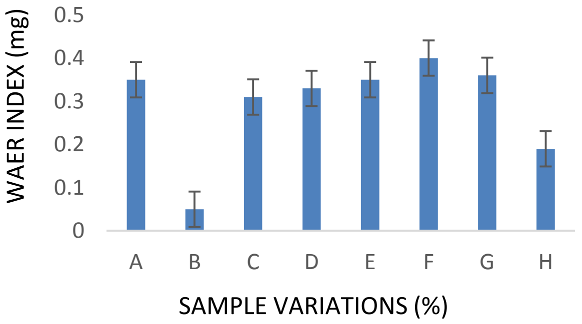

Fig. 7 *Wear index of hybrid coir fiber /chicken feather fiber reinforced composite*

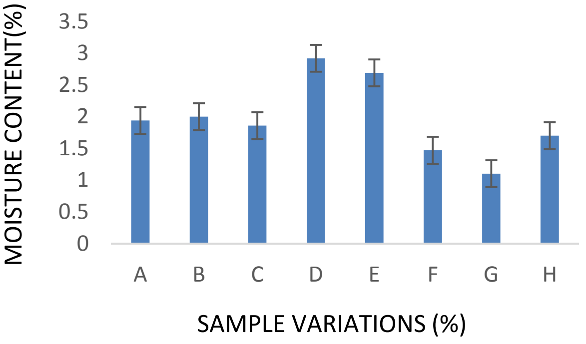

Fig. 8 *Percentage water absorption of hybrid coir fiber/chicken feather fiber reinforced epoxy composites.*

3.9 Surface Morphology

Fig. 9 and 10 show the SEM images of the fractured single and hybrid reinforced composites *B* and *F*. It was seen in Fig. 8 that fibers pull out was observed from the matrix cavity interface due to material rupture under stress. On the other hand, sample *F* in Fig. 10 shows good interfacial adhesion between the fiber and matrix and, this is due to proper polymer-fiber interactions. This confirms the reason for better property combination seen in sample *F*.

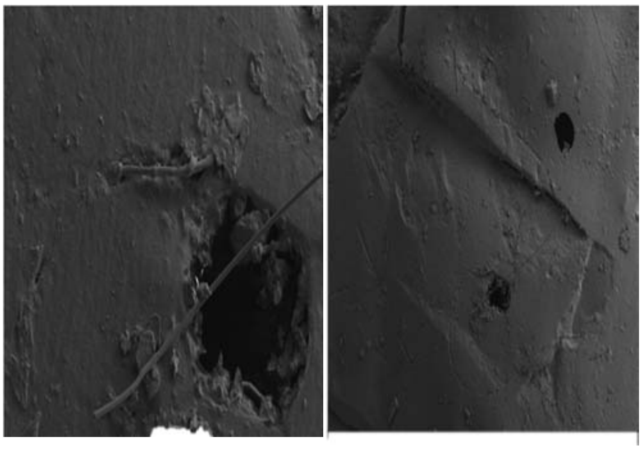

Fig. 9 *SEM images of coir fiber/chicken feather fiber reinforced epoxy composites with compositions B.*

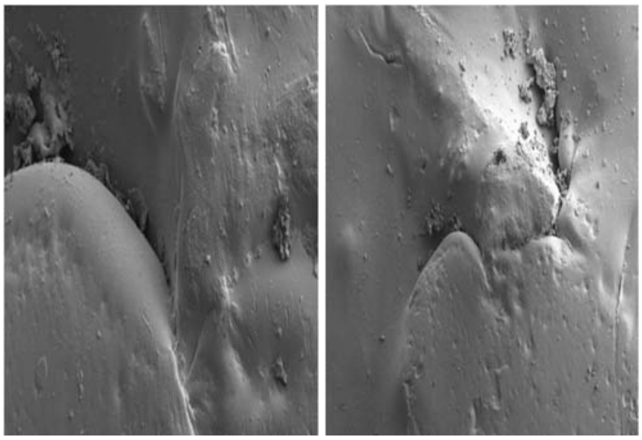

Fig.10 *SEM images of coir fiber/chicken feather fiber reinforced epoxy composites with compositions F.*

4. CONCLUSIONS

The effect of natural fibers from cellulosic and keratinous based (CF and CFF) on some selected properties of epoxy composites have been investigated. It was discovered that all the investigated properties were improved, mostly in sample denoted as F with 1 wt % CF and 2 wt % CFF. This sample gave optimum properties with respect to mechanical, thermal, wear and resistance to moisture absorption. Thermal insulating potential of the developed epoxy composites were highly improved with the blend of these bio-fibers which suggest their use as insulating materials where most other epoxy based composited might have failed. Coir fiber and chicken feather are good insulating bio-fibers and this has been demonstrated by the hybrid composite samples. Higher insulating property was achieved due to the presence of microporous CFF which reduces the solid conduction within the composite. The use of these agro-wastes will encourage the development of green composites that are highly desirable in automobile in the recent times.

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