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FULL PAPER

Effect of hybridization on mechanical, thermal and water absorption properties of biocomposite

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Environmental concern over synthetic materials and sustainability issues due to the reduction of fossil fuels have given rise to remarkable progress in the development of green products like biocomposites. Natural fiber is used as reinforcement in biodegradable, ecofriendly and economic composites. However, they lack desired mechanical properties at highly humid or aqueous environment, which limits their application in many fields. Hybrid biocomposites with more than one type of natural fiber has recently drawn great research due to their improved properties. This paper focused on the studies of mechanical, thermal and water absorption properties of pure woven cotton fiber/ polystyrene (WCF/PS) and hybrid woven palm-cotton fiber/ polystyrene (WPCF/PS) biocomposite. The mechanical properties of the samples were evaluated by a Universal Testing machine (UTM) and thermal properties by Thermo Gravimetric analyzer (TGA). Water absorption properties were analyzed by % weight gain method. The mechanical properties including tensile strength, tensile modulus and impact strength were found to be higher in hybrid WPCF/PS biocomposite. Higher thermal stability and less water absorption property were observed in the hybrid sample. This study reveals that improvement in properties could be achieved in biocomposite through hybridisation of palm fiber with cotton fiber, which would help to widen their research scope and commercial acceptability.

KEYWORDS

Woven cotton fiber; woven palm-cotton fiber; Polystyrene; hybrid biocomposite.

Introduction

Material engineering and design are greatly influenced by the booming of green products like biocomposites. Scientists and engineers have entrusted on utilizing bio fibers for their being constructive and cost-effective to produce materials suitable for different application sectors. In recent years biocomposites have received great acceptance in all fields of life such as, packing, construction, boats, machinery, office products, aerospace, sports, recreation equipment, structural components, medical, electrical and electronic industries [1-6]. Various types of natural fibers have been investigated as reinforcement for their use in polymers such as wood fiber, sisal, kenaf pineapple, jute, banana and straw. The use of natural fiber composites is promoted by their advantageous material properties in comparison with synthetic fiber like glass or carbon fiber composite [7]. Biocomposites have captured global interest due to their low prize, non-polluting nature, renewability, non-abrasiveness, impact strength, delicate and easy processability [8–13]. Despite having these advantageous properties, their applications are limited compared with petroleum-based synthetic products due to relatively low tensile strength, thermal stability and low stiffness [14,15]. The study of bio fibers as reinforcement has revealed that the properties of such composite can be improved by incorporating two or more fibers in a single matrix. This type of hybridization is one of the significant methods which helps to cover up many limitations of natural fiber reinforced composite. The lack in one fiber property can be adjusted with another one by choosing a suitable combination of fibers which would enable them to be a better substitute to synthetic composites [16-19]. Proper selection and design of fibers could produce cost-effective novel biocomposites with improved properties.

Woven fabrics as reinforcement are getting research interest due to their easy processing, good mechanical properties, good integrity and stability [20]. Woven hybrid fiber in the wrap and weft plain weave structure provides more balanced properties. Many studies have reported on excellent properties of woven hybrid fiber composite [21-24].

Karthik Aruchamy *et al.* [25] studied the mechanical properties of woven cotton fiber and hybrid cotton-bamboo fiber reinforced epoxy resin composite. They reported that hybrid cotton-bamboo fiber, with 45% fiber loading composite imparted better mechanical properties than pure cotton epoxy biocomposite. Boopalan *et al.* [26] analyzed mechanical and thermal properties of raw jute and banana fiber reinforced epoxy composites. There was improvement in tensile strength, flexural strength and impact strength on hybridizing jute fiber with banana fiber. They also reported reduction in moisture absorption in hybrid sample. Yahaya *et al.* [27] investigated Kenaf fiber reinforced hybrid composite in thermoset and thermoplastic polymer matrix and pointed out that hybridization has improved properties of composite. The ability to employ kenaf fiber in a variety of applications is increased by combining it with more than two fibers in hybrid composites.

Venkateshwaran *et al.* [28] analyzed mechanical and water absorption characteristics of woven jute/banana epoxy hybrid composites and found that mechanical properties such as tensile, flexural and impact properties of jute-banana hybrid fiber composite were much better than individual fiber reinforced pure composite

There are certain parameters which significantly contribute to the improved properties in hybrid composites such as proper selection of fibers, method of preparation, and the interaction between fiber and matrix. These criteria are very essential, as they might finally cause unanticipated consequences. Many researchers have found negative consequences of hybridization as a result of improper material selection, processing procedures, layer sequence in a hybrid structure, and loading patterns. Sreekala *et al.* [29] reported that hybridization resulted in the decrement in tensile strength and tensile modulus in the case of oil palm empty fruit bunch (OPEFB) fiber composite in very low and high fiber volume fractions. Zweben [30] predicted that on hybridizing high elongation fibers in low elongation fibers, the composite might behave like crack arrestors on a micromechanical level.

According to the rule of mixtures behaviour, Marom *et al.* [31] explored positive or negative hybrid effects in hybrid composites as a positive or negative deviation of a given mechanical property, which is based on a weighted average of the individual composite's unique features.

Considering the previous research works and increasing demand of novel biocomposites in various fields, it seems essential to study hybridizing cotton fiber with palm fiber in poly styrene matrix biocomposite. The present study focused mainly on analyzing the effect of hybridization on mechanical, thermal and water absorption properties of biocomposites. Cotton/cotton fiber and corresponding hybrid cotton-palm fiber reinforced in Poly styrene (PS) matrix composite were selected in this study since the fibers are available in nature and it is a cost-effective novel combination. This analysis can pave the way for further research and development of the material which would facilitate their commercial acceptability.

Experimental

Biocomposite samples prepared with pure woven cotton/cotton fiber material with 20% polystyrene and hybrid woven palm/cotton fiber material with 20% polystyrene were chosen for comparative analysis of mechanical, water absorption and thermal properties. Five samples from each type of biocomposites were selected for analyzing the following properties

Mechanical properties

The prepared samples were cut into rectangular dimensions in accordance with ASTM-882. The tensilestrength and tensile modulus of the samples were determined stretching under a cross-head speed of 5 mm/min.

Izod impact tester as per ASTM D256 standard was used for assessing the impact strength. Five samples were tested in each case and average value was applied for analyzing and comparing the mechanical properties of pure WCF/PS and hybrid WPCF/PS biocomposite samples.

Water absorption properties

Natural fiber reinforced composites are water absorbing in nature and their water absorption can be measured by weight gain method**.** The pure WCF/PS and hybrid WPCF/PS biocomposite samples were dipped in water at 23 °C as per ASTM D 570 standard test. First, the samples were cut into 5x5x2.5 mm size and the corners modified to prevent non uniform water diffusion. The samples were dried in an air oven at 60 °C for 2 hours. It was kept in desiccator for 24 hours and weighed (W1). The samples were then immersed in water bath for 24 hours kept at ambient temperature. The samples were removed from water, excess water dried by pressing with tissue paper and weighed (W2). Water absorption can be determined from % increase in weight using the formula.

$$\text{Weight Gain (\%)} = \frac{(W_2 - W_1)}{W_1} \times 100 \qquad \text{Eq(1)}$$

Thermal studies

The thermal stability and degradation properties of the samples with rise of temperature were analyzed by using a thermo gravimetric analyzer TGA-Q500 (Schimadzu Autograph, AG-Xplus series) under the following conditions: weight roughly by 10.00 mg; synthetic air flow by 60 mL/min; heating rate by 10 °C/min; and temperature range by 25-750 °C. Measurements are used to understand and compare thermal stability of both pure WCF/PS and hybrid WPCF/PS biocomposite materials.

Results and discussion

Mechanical properties

Mechanical properties like tensile strength, tensile modulus and impact strength are the most significant properties of the material to indicate its strength and stiffness. The average values of measurement for pure WCF/PS biocomposite and hybrid WPCF/PS bio composites are given in Table 1.

The results reveal that tensile strength, tensile modulus and impact strength increased the hybridisation of palm fiber with cotton fiber, indicating the effectiveness of the reinforcement. Cotton fibers had comparatively good tensile strength in wrap direction on hybridisation with tough palm fibers on weft direction complimented to its improved mechanical properties. Many studies about biocomposite have reported that mechanical properties depend on factors like nature of reinforcement, fiber volume, fiber ratio, structure of the fiber, fiber disbursement and fiber-matrix binding [32-38]. WPCF material showed tight, dense and compact weave pattern compared with pure WCF material.

The impct strength mainly depends upon the type of reinforcement and its adhesion with matrix.

TABLE 1 Mechanical properties of pure WCF/PS and hybrid WPCF/PS biocomposite

Biocomposite Samples	Tensile Strength Mpa	Tensile Modulus Mpa	Impact Strength KJ/m2
WCF/PS	17.829	374.481	12.272
WPCF/PS	18.118	612.656	18.233

From previous studies, it is clear that individual fiber characteristics highly contribute to impact strength properties apart from other parameters such as fiber ratio, structure, method of preparation, void content and geometry of the composite [39,40].

The comparatively tough palm fiber incorporation in the hybrid composite enhanced its impact properties. It is prominent from the results that the hybrid WPCF has a greater impact strength than pure cotton woven fiber-reinforced polystyrene composites and there is a 48.57% increase in value on hybridization.

Water Absorption Properties

All biocomposites are water absorbing in an aqueous environment or when immersed in water. This occurs due to hydrophilic lignocellulose material constituent present in them. This could have negative effect on many of their properties, hence Water absorption test is very significant for biocomposite. Water absorption behavior was analyzed by % weight gain and results are tabulated in table -2. The results indicate that water absorption is less in WPCF reinforced PS hybrid biocomposite. Cotton fibers have more cellulose content than palm fibers which has resulted in more % water absorption in WCF/PS biocomposite. It has almost 15% more water absorption than hybrid WPCF/PS biocomposite.

TABLE 2 Water absorption characteristics of pure WCF/PS and hybrid WPCF/PS biocomposite

Biocomposite Samples	Initial Weight (W1)	Final Weight (W2)	% Weight Gain
WPCF/PS	0.504	0.512	1.587
WCF/PS	0.482	0.4908	1.83

Thermal studies

Thermal stability test of the material is very important in various application fields. TGA results of the biocomposite samples (given in Fig-1) depict that there is considerable enhancement in decomposition temperature on hybridizing palm fiber with cotton fiber. Both initial and final decomposition temperature of the hybrid WPCF/PS biocomposite is higher than that of pure WCF/PS biocomposite. It is observed that the initial weight loss temperature of the hybrid increased to 308 °C from 290 °C and final decomposition temperature increased to 430 °C from 400 °C, on comparing initial and final decomposition temperature of pure WCF/PS sample. The major weight loss (about 70%) of the hybrid sample occurred around 430 °C indicating that hybridization has a positive effect and WPCF/PS biocomposites have good thermal stability.

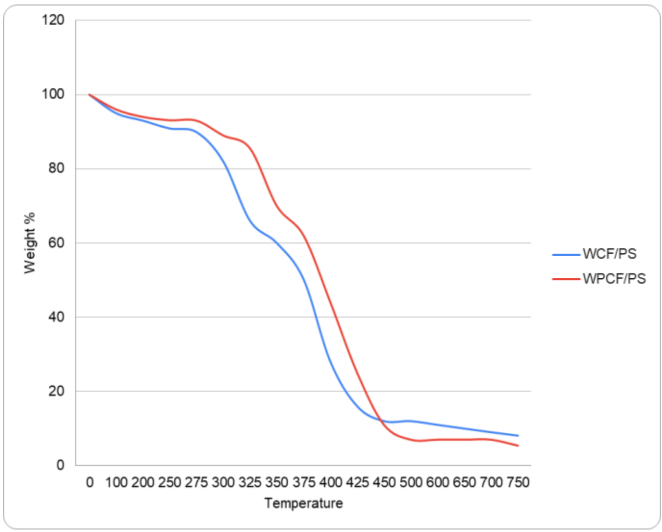

FIGURE 1 TGA curve of pure WCF/PS and hybrid WPCF/PS biocomposite

Conclusion

In this study, mechanical, thermal and water absorption properties of pure WCF reinforced PS biocomposite and hybrid WPCF/PS were discussed.

The results revealed that mechanical properties like tensile strength, tensile modulus and impact strength are found to be highest in the case of hybrid WPCF/PS biocomposite. There is 0.61% increase in tensile strength and 48.57% increase in impact strength compared with pure WCF/PS biocomposite.

Hybrid composite possesses comparatively better thermal stability and less water absorption capacity. Water absorption tests revealed that pure WCF/PS biocomposite has about 15% more water absorption than hybrid WPCF/PS biocomposite. This reduction in value of water absorption in the hybrid WPCF/PScomposite is a prominent positive effect of hybridization since their applications in various fields are limited due to their hydrophilic and water absorption nature. This study recommends hybridization of palm fiber with cotton fiber for improved mechanical, thermal and water absorption properties in biocomposite.

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Conflict of interest

The authors declare there is no conflict of interest.

The authors' contributions

Sujaya Gangadharan has carried out the experimental part and prepared the manuscript and Venkattappan Anbazhagan has contributed in the preparation and revision of manuscript.

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