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ORIGINAL ARTICLE

Effect of *Luffa cylindrica* fiber and particulate on the mechanical properties of epoxy

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Abstract

This study examines the effect of addition of *Luffa cylindrica* fiber (LCF) and *Luffa cylindrica* particulate (LCP) on the properties of epoxy resin. *Luffa cylindrica* fiber treated with 8% NaOH and of 2, 4, and 6% weight fraction was used to reinforce epoxy resin via hand lay-up method. Hybridization of the fiber and particulate was also done with the particulate having a constant weight fraction of 10% whereas the fibers were varied as in the mono-reinforced *Luffa cylindrica* fiber composite. The samples were machined for mechanical and microstructural analysis. Result showed that addition of the reinforcement led to an improvement in mechanical properties. However, the hybrid was seen to showcase better properties compared to the fiber-reinforced composite with the hybrid sample of composition 4 wt% LCF and 10 wt% LCP exhibiting the highest tensile and flexural strength of 13.489 MPa and 20.3 MPa, respectively. Microstructural analysis showed excellent homogeneity with few voids and better adhesion between the reinforcement and matrix. These results show that this composite can find application in the interior and exterior parts of automobiles as well as in household wares like flower pots.

Keywords *Luffa cylindrica* fiber · *Luffa cylindrica* particulate · Epoxy resin · Hand lay-up · Hybridization · Mechanical properties

1 Introduction

Polymer matrix composites have proven to be materials with high prospect due to varying combination of good properties that they have shown to possess. With wide range application in aerospace, automobile, biomedical engineering, among others, these sets of materials are becoming indispensable in the world of engineering [1–3]. Over the years, synthetic fibers like carbon fiber, glass, aramid, and some petroleum-based fibers have been the main reinforcement material for this class of composite. However, these inorganic fibers though possessing enviable properties also have heavy shortcomings that are putting other kinds of fibers at their expense. These include being non-biodegradable, non-recyclable, and costly and they even pose health hazards on inhalation [4]. With dwindling petroleum resources and increasing concern towards environment issues, a look out for new set of materials that are not only sustainable, environmental friendly but also cost effective which will serve as substitute or possible replacement for synthetic fibers are on the rise [5]. Natural fibers have not only come in handy in this prospect but have also shown extreme promise. With additional properties like light weight, renewability, relative high specific strength, and modulus, natural fibers are seen as possible replacement for synthetic and petroleum-based fibers as reinforcement in polymer matrix composite [1, 6]. Natural fibers like flax, sisal, jute, coir, hemp, etc. have been proven to perform excellently as reinforcement material in polymer matrix composite [7–10] thus opening a door of research for newer and rarely known fibers. Among these fibers that are currently receiving attention is *Luffa cylindrica*.

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Luffa cylindrica commonly called Luffa or sponge gourd is a fibrous plant containing black seeds and belongs to the Curcubitaceae family [11]. It is a vigorous, climbing tree, with a square stem and tendrils up to 10 cm long. The leaves have a rough surface and may be up to 25 × 25 cm. It grows widely in Africa and Asia where it is used as food and has also been seen to have medicinal values [11–13]. *Luffa cylindrica* fibers contain about 10.6–11.2% lignin, 19.4–22% hemicelluloses, and 60–63% alpha cellulose [14–17]. In Nsukka, Nigeria, the fruit is known as Ogbonga and is used as local sponge due to its netlike structure and stiffness. However, the total quantity of *Luffa cylindrica* locally used in this regard is nothing compared to annual quantity of the fruit produced yearly. The fruit is brown when mature and dries on the vine to develop an inedible sponge-like structure. Many works have been carried out on the use of this naturally matted fiber as reinforcement material for polymers with promising results reported. With a density of 0.56 g/cm^3, this fiber stands above many other natural fibers in producing composites of low weight but high strength [18]. Addition of chopped Luffa fiber to epoxy has been seen to improve mechanical properties like tensile, compressive, flexural strength, and impact energy with 40 wt% fiber showcasing optimum mechanical properties [19]. Mohanta N. and Acharya S.K. while using single, double, and triple layered *Luffa cylindrica* fiber to reinforce epoxy resin observed that tensile, flexural, impact strength, percentage elongation and hardness increased up till double-layered composite before decreasing at the triple-layered composite. This was ascribed to poor fiber wetting leading to poor fiber-matrix adhesion and thus development of microcracks. Density, tensile modulus, and inter-laminar shear stress increased with the number of fiber layers. Erosion behavior of the composites produced were studied based on impingement angle and impact velocity of the erodent (silica sand particles). They also observed that erosion rate increased with increasing impingement angle with maximum angle obtained at 45° for the single- and double-layered composite and 60° for the triple-layered fiber composite thus showing that the composite exhibited a semi ductile behavior [18]. Mani P. et al., in comparing the tensile and flexural properties of matted and chopped Luffa fiber–epoxy–reinforced composite, observed that matted Luffa fiber showed better flexural strength whereas the chopped luffa fibers exhibited higher tensile strength. However, the volume fraction of the reinforcement was seen to play a role as flexural strength increased with volume fraction in the two shapes of the fiber [20].

Natural fibers like *Luffa cylindrica* being lignocellulosic are known to contain wax, fatty acids, hemicellulose, and lignin [21]. Presence of these compounds leads to difference in polarity between the fibers and matrix and as such poor interfacial bonding [22]. This is one of the major challenges facing natural fibers. Various methods like mercerization, acetylation, silane treatment, ultraviolent radiation, corona treatment among others have been proposed to solve this issue with varying degrees of success [23]. Among these, alkali treatment remains one of the most cost-effective and sort after method. This is because alkali treatment promotes ionization of hydroxyl group to alkoxide thus leading to increase in surface roughness, and increase in the amount of exposed cellulose. This leads to better mechanical interlocking and an increase in the number of reaction sites which again leads to better adhesion between treated fiber and matrix. Also, fibrillation occurs leading to an increase in aspect ratio and surface area leading to improved wettability [21, 24]. Sabarinathan P. et al. from their work on the properties of a hybrid composite consisting of *Luffa cylindrica* and Flax with epoxy resin as matrix showed that not only did tensile, flexural, and impact strength improve but also treated fibers performed better than its untreated counterpart [25]. Chemical treatment was seen to alter the hydrophilicity of the fiber thus improving fiber/polymer interaction [26]. Alkylated fiber was seen to showcase highest tensile strength compared to acetylated fibers [27]. Improvement in the properties of Luffa fiber–reinforced composite due to fiber treatment has also been reported by [21, 24, 28].

Though mono-reinforced composites like *Luffa cylindrica* fiber–reinforced composite have been seen to showcase enhanced properties; hybrid composites, however, have been observed to show more surpassing properties [28, 29]. The effect of hybridizing luffa fiber with some fibers/reinforcement has been studied. Sakthivel M et al. explored the potential of using luffa fibers/coir in particulate form as reinforcement for a polymer like polypropylene. They observed that addition of both lignocellulosic-based reinforcement led to an improvement in mechanical properties and which goes on to showcase the compatibility between the two materials [29]. Srinivasan C. et al. work on the effect of fiber treatment and addition of SiO_2 nanoparticles on the properties of the composite. Fiber treatment was seen to improve quality of fiber/matrix interface whereas addition of SiO_2 nanoparticles improved mechanical properties [30]. Panneerdhass R. et al. used Luffa fiber and groundnut shell particles to reinforce epoxy resin. Tensile, compressive, flexural, and impact strength were observed to volume fraction of the reinforcement [31]. However, the effect of hybridizing Luffa fiber with Luffa particulates remains a mystery with promising result due to the already existing synergy; being the same kind of reinforcement material. Moreover, the advantages of reinforcing with fibers and particulates will be easily exploited.