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ORIGINAL ARTICLE

Influence of Kaolin particulate and Luffa cylindrica fiber on the mechanical properties polyester matrix

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Abstract

Polymeric materials are used in different industrial applications because they retain good environmental properties, low-cost, and easy to produce compared to conventional materials. This study investigated the effect of adding Kaolin particulate (KFP) and Luffa cylindrica fiber (LCF) on the mechanical properties of polyester resin. Luffa cylindrica fiber was treated with 5% NaOH, varied in weight fraction (5, 10, and 15%wt), and was used to reinforce unsaturated polyester resin using the hand lay-up method, whereas, for the hybrid composite, Kaolin particulates were kept constant at 6wt% fraction while the fibers varied as in the mono-reinforced composite. The samples were machined for mechanical analysis. Analysis of the result revealed that the reinforcement has enhanced greatly the mechanical properties of polyester composites.

Keywords *Luffa cylindrica fiber* · Kaolin particulate · Polymer matrix composite

1 Introduction

The demand for polymer composites reinforced or filled with natural fibers and powders for various industrial applications (construction, automobiles, furniture, and sporting goods) is growing because they retain good environmental performance, low cost, and ease of production compared to traditional materials [1–3]. They have low price and low weight, and they minimize the impact on environmental pollution; these are the key reasons for the rapid development of polymer composite materials. Recent research efforts are aimed at finding alternative fillers to replace inorganic fillers [4]. In addition to inorganic fillers, the use of natural fibers (organic fillers) also has the following advantages: low-cost, low density, non-abrasive, biodegradable, availability from natural resources, recyclability, and renewable natural resources [5, 6]. Natural fiber–reinforced polymer (FRP) can solve efficiency and environmental issues.

Luffa cylindrica is a naturally occurring cucumber vine in many countries. Luffa's young cylindrical fruits are edible and contain a number of compounds, including ribosome-inactivating flavonoids, phenols, triterpenes, and proteins. For medicinal purposes, such as immunostimulants and anti-inflammatory agents, the Luffa fruit has been used effectively [7]. Luffa sponge has been successfully used in the biosorption process of heavy metals in wastewater and is an essential natural fiber. This emerging cash crop has the full potential to improve the economies of developing nations [7–10]. There are 84% holocellulose, 66% cellulose, 17% hemi-cellulose, 15% legnine, 3.2% extractives, and 0.4% ashes in Luffa fiber's physical properties. The physical properties of Luffa fiber are 820 kg/m^3 mass, 25–60 μm diameter, and 59.1 crystallinity index [11–13]. Oboh et al. have given functions and applications of Luffa fiber in agriculture, medicine, and science and technology. Msahli et al.'s studies have shown that the bending strength and adhesion between Luffa fibers and the polyester matrix can be strengthened by acetylation and cyanoethylation of Luffa fibers.

In order to improve performance and reduce costs, fillers are used with different commodities and engineering polymers. The use of inorganic mineral fillers in plastic resins will

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increase the different physical properties of the material, such as mechanical strength and modulus. Generally, the mechanical properties of particle-filled polymer composites largely depend on the size, shape, distribution of filler particles in the polymer matrix, and degree of interfacial adhesion between filler and matrix [14–17]. Calcium carbonate, kaolin, mica, and talc are most commonly used as fillers to minimize production costs and enhance thermosetting properties such as crystallinity, stiffness, flexural modulus, resilience, dimensional stability, electrical conductivity, and thermal conductivity. In order to prepare particle composites, Al-Asade and Al-Murshdy studied the addition of kaolin into an unsaturated polyester matrix. The addition of 3–9% of kaolin to the unsaturated polyester resin indicates that the kaolin acts as a binder, and the resulting composite material acts as a particle strengthening agent, resulting in the improvement of the mechanical properties of the unsaturated polyester [18]. Ahmed et al. studied another kaolin composite polyester. In this study, a polymer composite made of diethylene glycol and untreated kaolin (based on polyethylene terephthalate (PET) waste derived from unsaturated polyester) was tested. Thermal and chemical methods have been carried out to process kaolin. These treatments affect the mechanical and electrical properties of Kaolin-filled polyester composites [19]. These reports motivated us to consider the inspiring possibility of incorporating the kaolin particulates and Luffa cylindrical fiber in polyester resin to study their effects on the mechanical properties of the matrix.

The hybridization of Luffa cylindrica fiber with Kaolin particle has been utilized to enhance the properties of composites. A wise choice of matrix and reinforcing phase contribute to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials. Improving the properties of polymers and their composites by adding particulate filler materials in industrial and structural applications has shown great promise and has recently attracted great attention. Sakthivel M et al. researched the feasibility of using Luffa fibers/coir as reinforcement for a polymer such as polypropylene in particulate form. They found that the addition of both reinforcement materials based on lignocellulose resulted in improved mechanical properties, and there was continuous proof of consistency between the two materials [20]. Srinivasan C. studied the effect of fiber treatment and the addition of SiO_2 nanoparticles on the properties of composite materials. It was found that the mechanical properties of Luffa fiber epoxy composites filled with SiO_2 nanoparticles increased by 2% than unfilled Luffa fiber epoxy composites. Panneerdhass R. et al. used Luffa fiber and peanut shell particles to reinforce epoxy resin. It was found that the tensile, compressive, flexural, and impact strength were observed at the reinforcement volume fraction [21]. Fayomi O. et al. studied the effect of fiber and particles of Luffa cylindrica on the mechanical properties of epoxy resin. The result is that the mechanical and morphological properties of epoxy resin are modified by the addition of reinforcement. The composite material surface suggests that a higher weight can cause a brittle fracture [22].

Based on the literature reviews, the use of Kaolin particulate and Luffa cylindrica fiber together as reinforcement has not been examined in the production of composite. The present work aims to investigate the effect of Kaolin particulate and Luffa cylindrica fiber on polyester composites. Tensile strength, flexural strength, impact strength, and hardness values were measured for both unfilled and Kaolin-filled Luffa/polyester composites. The results of the mechanical properties are presented and discussed.

2 Experimental detail

2.1 Materials and equipment

The reinforcement materials applied in this research are Luffa fiber and Kaolin filler, and the matrix is a polyester resin.

2.2 Reinforcement preparation

The Luffa cylindrical fiber was treated at 80°C with a 5% NaOH solution. It was washed with distilled water and dried at room temperature for 24 h from the outside surface after treatment to extract lignin, oil, and Luffa fiber wax, and then dried at room temperature. After drying in the sun for a few days, a fibrous mat (130 mm by 120 mm) was cut out of the outer core of the Luffa fruit shell, mounted further between two flat wooden plates, and straightened to an even thickness by applying a uniform compressive load with the mechanical bench vices for a few hours. Kaolin was used as a microparticulate filler and pure unsaturated polyester was used as the matrix material. Kaolin particulate was procured from the Department of Chemical Engineering, Ahmadu Bello University, Zaria, Nigeria.

2.3 Composite fabrication

To create the composite, a conventional process called the hand lay-up process was used (Plate 1). The hand lay-up method has been a widely studied method of manufacturing natural fiber–based composites because of its flexibility, cost-effectiveness, and durability, which is economically feasible for developing countries and less financially supported by universities and colleges. Fiber (Luffa) was varied at weight fraction (0, 5, 10, and 15%wt) for the fiber-reinforced composite, whereas for the hybrid composite filler (Kaolin) was kept constant at 6wt% fraction while the fiber (Luffa) was varied as in the mono-reinforced composite. The required quantity of polyester matrix and Kaolin was weighed using

Plate 1 Graphical representation of the composite fabrication

an electronic weighing balance and put in a 200-ml glass beaker. In order to prevent aggregation and to achieve a faster and more accurate distribution of the filler in the polyester resin matrix, the composite mixture was thoroughly stirred for 10 min using a long glass rod. Subsequently, methyl-ethyl-ketone-peroxide (MEKP) catalytic converter was introduced using a disposable syringe at a ratio of 10 ml of polyester to 0.2 ml of the catalytic converter and stirred for around 2 min, after which the cobalt naphthenate accelerator was applied at a rate of 10 ml of polyester to 0.1 ml of accelerator and stirred for another 2 min. The mold release layer was laid over the wooden molds prepared for the tensile, flexural, impact, and hardness tests of specimens (120 × 5 × 15 mm, 100 × 30 × 10 mm, 100 × 10 × 10 mm, and 10 × 10 × 10 mm respectively) to extract the composite material quickly and easily, and the release spray was applied to the inner surface of the mold. A thin layer of the mixture was poured after keeping the mold on the plywood, followed by the distribution of the fiber laminate onto the mixture. The mixture was applied over the fiber laminate, and the process was repeated in order to achieve the desired thickness. Care was taken to ensure correct wetting between the matrix and reinforcement before a compressive load of 150 KN was applied to ensure proper bonding and to push out trapped gases. The samples were allowed to cure for 72 h and the mold samples were taken for mechanical testing. The label and description of the composite samples are indicated in Table 1.

Table 1 Detailed designation and composition of composites

Label	Composition
C1	Polyester + Luffa fiber(0 wt%)
C2	Polyester + Luffa fiber (5 wt%)
C3	Polyester + Luffa fiber (10wt%)
C4	Polyester + Luffa fiber (15 wt%)
C5	Polyester + Luffa fiber (5 wt%) + Kaolin (6 wt%)
C6	Polyester + Luffa fiber (10 wt%) + Kaolin (6 wt%)
C7	Polyester + Luffa fiber (15 wt%) + Kaolin (6 wt%)

2.4 Mechanical testing

2.4.1 Tensile strength result

Tensile test samples were machined to a dumb-bell shaped of dimension 100.0 × 15.0 × 5.0 mm according to ASTM D638 and claimed between the upper and lower jaws of the Monsanto tensometer (type "W") and the machine was loaded. Three samples were tested for each composite specification and the average found. The samples were stretched in the device until the samples ruptured. The values of the breaking load and elongation were taken accordingly. The test was repeated three times for each sample of the composite and the average value was recorded.

2.4.2 Flexural strength result

The flexural test was carried out on specimens measuring 100.0 × 30.0 × 10.0 mm according to ASTM (D790) using a computerized Instron 3369 Universal Testing Machine with a load cell capacity of 50KN. Three samples were tested for each composite specification and the average found. The three-point bend flexural test method was used with a cross-head speed of 5 mm/min and a span length of 65mm. Samples were positioned on the support span and the load was applied to the center by the loading nose producing three-point bending. The test was stopped at 5% deflection.

2.4.3 Hardness test

The hardness test was carried out on each specimen according to ASTM C1327 with a dimension of 10.0 × 10.0 × 60 mm. The indentation technique using a Vickers diamond pyramid indenter on the microhardness tester was used. The measurement was done on the surface by applying a 0.3-kg load for 15 s. Three Vickers hardness readings were taken for each sample and the average values for the test samples were used as the illustrative values.

2.4.4 Impact test

The impact test was carried out on samples with a Charpy impact testing system with a capacity of 15J for polymer composites and 25J for metal composites at room temperature of model number 412. Test samples with a dimension of 100.0 × 10.0 × 10.0 mm were produced in accordance with ASTM 2000. Three samples were tested for each composite specification and the average found. The sample was placed on the machine prior to the test and the pendulum was released to calibrate the machine. The test samples were then horizontally clenched in a vice and the freely swinging pendulum given the requisite force to crack the bar. The value of the angle at which the pendulum swung before the test sample was broken corresponded to the value of the energy that was consumed when the sample was broken and was read from the machine's calibrated scale.

3 Results and discussion

3.1 Tensile results

The effect of fiber loading in reinforced Luffa cylindrica fiber (LCF) composites on both with and without Kaolin filler (KF) is seen in Fig. 1. It was observed that the tensile strength of the composites decreases with the increase in fiber loading in both cases, i.e., with and without micro-filler. Tensile strength ranged from 12.11 to 9.17 MPa for the mono-reinforced composite whereas the hybrid composite shows values ranging from 15.32 to 11.46 MPa. It can also be observed that the maximum value of 12.11MPa was given for the mono-reinforced composites of C2 samples with 5wt of LCF with a 72.02% increase compared to the control sample C1 (0wt% of reinforcement), while for the hybrid composite of sample C5 with 5wt% LCF and 6wt% KF gave an optimum value of

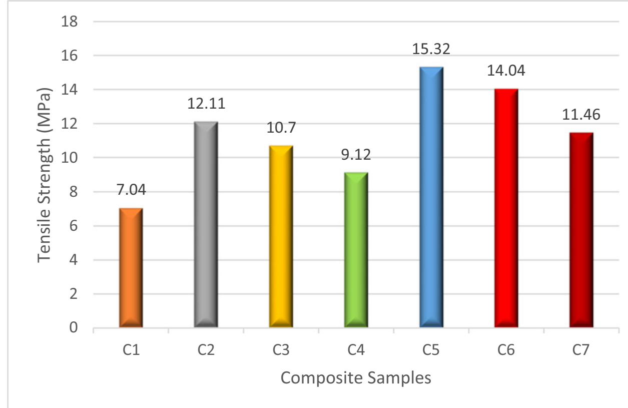

Fig. 1 Tensile Strength of the composites

15.32 MPa compared to other filled composites with 117.61% improvement in compared to C1 and 26.51% to C2. This can be attributed to the effectiveness of the addition of particulate to fiber-reinforced composites. The general expression of the results indicates that the composite material developed from materials based on Kaolin-Luffa has a higher tensile strength than that developed from materials based on Luffa cylindrica fiber only. Ichetaonye SI. et al. obtained similar findings where the tensile strength increased up 20wt% fiber loading before decreasing.

3.2 Flexural strength

The flexural test measures the strength needed under three-point loading conditions for bending a beam. The data is also used to select materials for components that will carry loads without flexing. The results are as shown in Fig. 2 from which it can be seen that all the composites possess better flexural strengths than the control sample. It was also noticed that the composite of sample C7 with 15wt% LCF and 6wt% KF reinforcement displayed the best flexural strength of 101.25MPa comparing to other hybrid composites, with 183.62% and 90.7% improvement compared to control

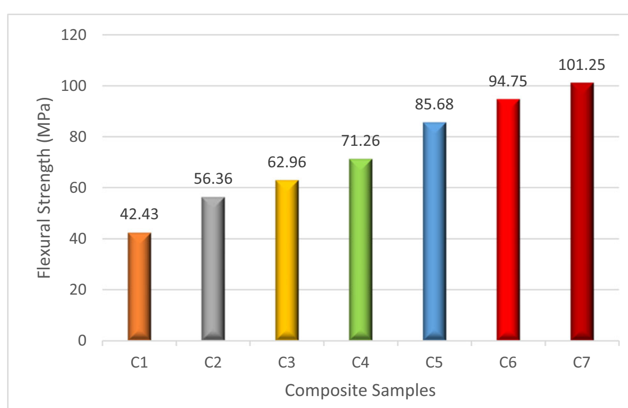

Fig. 2 Flexural strength of the composites

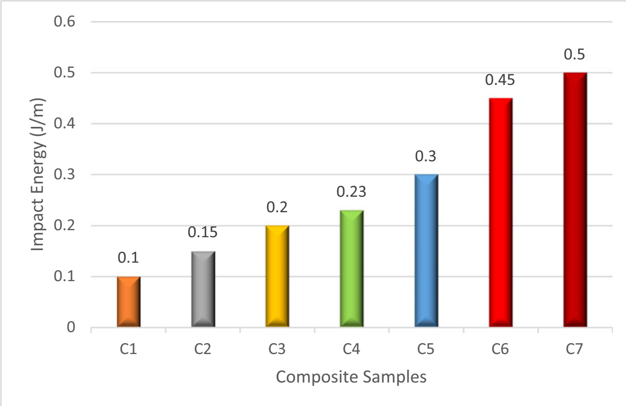

Fig. 3 Impact energy of the composites

sample and sample C4 of mono-reinforce composites. This is due to the addition of Kaolin particulates. This also goes in line with the observation of Vinay et al. (2016) where C7 (15% fibers loading) exhibited maximum flexural strength (72 MPa) when compared with other filled and unfilled composites.

3.3 Impact strength

The impact test results shown in Fig. 3 indicate that in the Luffa fiber–reinforced composites materials, whether with or without Kaolin filler, fiber loading led to an improvement in the impact energy of the matrix material. It was observed that the impact energy of the composites increases with the increase in fiber loading in both cases, i.e., with and without micro-filler. Impact energy ranged from 0.15 to 0.23J/m for the mono-reinforced composite whereas the hybrid composite shows values ranging from 0.3 to 0.5 MPa. It was noted as well that the mono-reinforced composites of samples C4 with 15wt% of LCF gave the maximum value of 0.23J/m with a 56.5% improvement compared to control sample C1 (0wt% of reinforcement), while the hybrid composite of sample C7 with 15wt% LCF and 6wt% KF gave an optimum value of 0.5J/m compared to other filled composites with 80% improvement compared to C1 and 54% to C5. The strong bonding strength between micro fillers, matrix, and fiber and the stability of the molecular interface result in more energy being absorbed and distributed and more effectively prevent cracks from initiating early. This also goes in line with the observation of Vinay et al. (2016) where C7 (15% fiber loading) exhibited maximum impact strength (8 joules) when compared with other filled and unfilled composites.

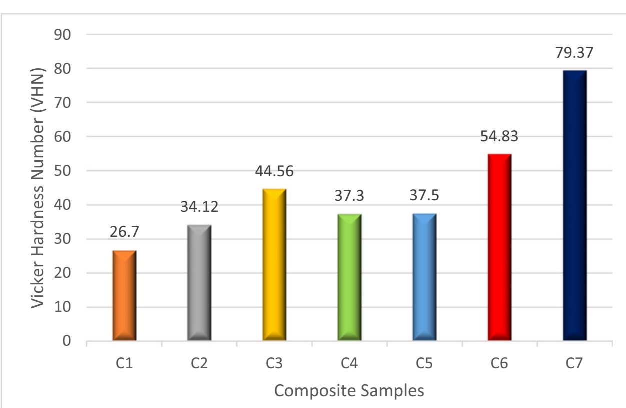

Fig. 4 Hardness number (VHN) of the composite

3.4 Hardness test

Vickers hardness test has been performed on the composite samples. Figure 4 shows that compared to other filled and unfilled composites, the hardness value of hybrid composite of C7 sample with 15wt% LFC and 6wt% of KF reinforcement exhibited a maximum hardness number of 79.37 HVN. This may be attributed to the uniform dispersion of Kaolin particles and the decrease in the distance of interparticle in the matrix, which increases the indentation resistance of composites. It can be observed that with the rise in fiber filling, the hardness value of the composites increases in both cases, i.e., with and without micro-filler. This aligns with the findings of Vinay et al. (2016) where mechanical properties like hardness reached a peak at an optimal weight fraction before decreasing.

4 Conclusions

Luffa fiber–reinforced polyester composites filled with or without kaolin filler were investigated. The following findings were observed:

1. The addition of Kaolin filler in the Luffa fiber matrix modifies the mechanical properties of polyester.
2. Hybridization of fiber and filler gives better performing composite with 5wt%LCF-2wt%KF hybrid composite, showcasing the best combination for tensile strength while 15wt%LCF- 6wt%KF hybrid composite showcasing the best combination for impact energy, flexural strength, and hardness test properties.
3. The current study reveals the promising potential of Kaolin-luffa-reinforced composites for industrial lightweight engineering and outdoor applications, including automotive parts and constructional panels

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Author contribution All authors contributed significantly to the work in accordance with the order provided

Data availability Materials are commercially available at a reasonable cost and quality result was obtained

Code availability Software application

Declarations

Conflict of interest The authors declare no competing interests.

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