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Water absorption and mechanical behaviour of green fibres and particles acting as reinforced hybrid composite materials

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This paper highlights the results of an experimental study on the preparation and characterization of *Luffa cylindrica* fiber (LCF) and groundnut shell particle (GSP) reinforced phenol-formaldehyde (PF) hybrid composites. The amount of LCFs was fixed at 25 wt%, while the amount of groundnut shell particles ranged from 0 to 25 wt%. Observations were made regarding the water absorption and thickness swelling behaviour of prepared hybrid composites. In addition, the mechanical behaviours of hybrid composites have been studied under both dry and wet conditions. In comparison to dry conditions, the mechanical properties of the hybrid composites were lower when they were wet. Hybrid composites comprising 25% *Luffa cylindrica* fibre and 15% groundnut shell particle (25LCF/15GSP) exhibit the highest level of mechanical properties under both conditions. The percentages of water absorption and thickness swelling increase as groundnut shell particles increase. The composite 25LCF/25GSP exhibited the highest percentage of water absorption and thickness swelling. Compared to date palm leaf (DPL)-reinforced composites, 25LCF/15GSP showed more significant mechanical and physical properties. We concluded that the inclusion of groundnut shell particles in LCF/PF composites substantially improved the mechanical properties of the hybrid composite. The range of increment, however, was narrower under moist conditions compared to dry conditions.

Keywords: *Luffa cylindrica fibre, groundnut shell particles, phenol-formaldehyde, water absorption, mechanical properties, date palm leaf*

1. Introduction

In recent years, the use of biologically natural fibres and particles as reinforcements for thermoplastics and thermosets has gained increasing attention. A great deal of research has been conducted worldwide on the utilisation of natural fibres (banana, Roselle (*Hibiscus sabdariffa*), coir, etc.) and particles (coconut shell particles, groundnut shell particles, etc.) as reinforcing materials for the manufacture of various polymer composites. Bio-natural cellulose fibres and particles have a variety of advantages over synthetic fibres and particles, including low cost and density, superior mechanical characteristics, greater specific strengths, lower impact on the environment, and lower levels of health hazards and power usage. Additionally, they have a high level of hardness [1–3].

Among the many types of organic fibre, the porous cucumber, or *Luffa cylindrica*, is a typical material that belongs to the cucurbits species and can be found in a variety of locations in South India. Due to its complex fibre structure, dehydrated *Luffa* berry typically takes the form of interwoven mats. Since the organic *Luffa cylindrica* mat possesses remarkable strength, toughness, and load-bearing capability, it has been successfully

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utilised as a naturally accessible fibrous substance in the mechanism of removing hazardous chemicals from wastewater. This harvest has the potential to boost the economies of emerging nations like India. *Luffa cylindrica* fiber (LCF), like other natural fibers, comprises cellulose (57.51%), hemicellulose (29.47%), lignin (20.45%), and extracts (8.83%) [4]. Numerous researchers have been studying LCF-reinforced polymer composites with the objective of characterizing their properties [5–9]. The effects of alkali treatment on the mechanical properties of an LCF-reinforced epoxy composite were studied by Sathish Kumar et al. [10]. The mechanical properties of the composites were found to be improved by the alkaline treatment compared to the glass fibre reinforced polymer composite. Mehra et al. [11] studied the influence of LCF and coir fibre contents on the mechanical and water absorption properties of epoxy composites. The results demonstrated that coir increases tensile and impact strength while LCF content increases flexural strength. When the LCF and coir fibre content were both the same in weight, the moisture resistance was maximized.

Moreover, India is the world's second largest groundnut producer. Groundnut is India's most important oilseed in terms of production. The shell composes around 25% to 35% of the pods in groundnut. The groundnut seeds comprise the remaining portion (65%–75%). Every aspect of the groundnut is commercially beneficial. The shell of the oil-rich peanut is a waste portion that holds lot of energy and can be used as a biomass fuel. The groundnut shell is a natural plant particle that is employed in the development of macro- to nano-particles products. The groundnut shell contains cellulose (35.7%), hemicelluloses (18.7%), lignin (18.7%), and other compounds (5.9%) [12]. Several researchers have attempted to use groundnut shell particles as reinforcement fillers in polymer matrix composite [13–15]. The ground nutshell powder improves the strength of recycled polyethylene materials and also improves the bio-degradability [16]. The hybridization of rice husk and groundnut shell particles exhibit better strength [17]. Waste groundnut shell particles and coir fibre-reinforced epoxy composites were developed, and their mechanical properties were examined by Potadar and Kadam [18] based on an alkali treatment. The study concluded that, in terms of mechanical qualities in particular, coir fibre composites are superior to groundnut fibre composites. Nyior et al. [19] investigated the mechanical properties of composites made of raffia palm fiber and groundnut shell particulate/epoxy (RPF/GSP/E). Hand lay-up was used to make the hybrid composite with additions of 10% to 50% of RPF and ground GSP in a ratio of 1:1. The mechanical characters of polylactide composites improved significantly from reinforcement with the groundnut shell particles [20]. Groundnut shell particles and its derivatives were found to be a sustainable material for construction applications [21]. The best mechanical properties were found in the RPF/GSP/E composite with a 40% loading. Based on the literature, LCFs, and GSPs were employed to reinforce PF in this study to create LCF/GSP/PF hybrid composites. The mechanical properties of the composite, including tensile, flexural, and impact behaviour, as well as water absorption behaviours, are investigated on the basis of the weight percentage of GSPs. Dry composite mechanical properties were compared to wet composite mechanical properties.

2. Investigation details

2.1. Materials

The waste *Luffa cylindrica* outer skins were purchased from the local village (Mills Krishnapuram) of Tamil Nadu, India, and extracted manually, as shown in Figure 1. Then, the extracted *Luffa cylindrica* fibres were washed, using 20 litres of distilled water, and sun-dried for a period of three days to remove viscous lignin substances. Following the process of sun-drying, it is ensured that the fibres were fully dry by visual examination and by touch. Then, the fibres were separated into a mat-shaped form. Figure 2 illustrates the extraction process of LCFs. LCFs were used as the primary reinforcement in composite preparation. Groundnut shell particles with a diameter of 0.3 mm were

Fig. 1. Digital image of (a) Mature *Luffa cylindrica* plant fruit; (b) waste outer skin of *Luffa cylindrica* fruit; (c) extracted *Luffa cylindrica* fibre

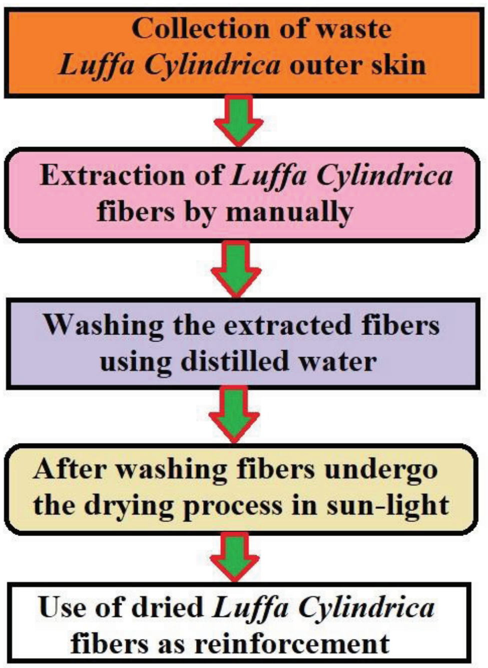


Fig. 2. Schematic diagram of the extraction process of *Luffa cylindrica* fibre

obtained from Meenambigai Agri Farm in Madurai, Tamil Nadu, India, and employed as secondary reinforcement in this investigation. In order to fabricate composites, PF resin was utilized as a matrix. Divinylbenzene (C10H10), an aromatic compound with two vinyl groups (CH_2=CH-) attached to a benzene ring was used as the cross-linking agent and hydrochloric acid was used as the acidic catalyst for polymerization. All of these materials were acquired from GVR Enterprise in Madurai, Tamil Nadu, India.

2.2. Preparation of hybrid composites

A steel mould measuring 150 mm $\times$ 20 mm $\times$ 3 mm was used for fabricating the hybrid composites using a hand lay-up technique. Wax was used to cover the mould before production so that the composite could be removed without much effort. Then, the pre-weighed reinforcements (LCF and GSP) were placed in the mould cavity, and the necessary quantity of PF resin was mixed with a cross-linking agent (divinylbenzene) and an acidic catalyst (hydrochloric acid) at a ratio of 100:2:1.5. To ensure that the resin matrix penetrated the reinforcements and the homogeneous mixing of resin and reinforcements, the mould box was subjected to mechanical shake or vibration and was kept open for a few minutes after the resin matrix had been poured. The entrapped air was pressed out with a roller. The mould was then sealed and left to cure for 24 hours at room temperature. The sheet was taken out from the mould and cut into test specimens as per the ASTM standards for a tensile test with the dimensions of 165-mm overall length, 50-mm gauge length, and 3.2-mm thickness. As per the ASTMD790-17 standard, the flexural specimens were cut with the dimensions of 127-mm length, 12.7-mm width, and 3.2-mm thickness.

2.3. Testing of hybrid composites

To conduct a tensile test, hybrid composite samples were cut according to the ASTM D638-14 standard [22]. The computerized FIE Universal Testing Machine (UTM) UTE 40 HGFL manufactured by Genesiss Engineers, India was used to test the material for tensile properties. To ensure the reliability of the results, five specimens of each composition were produced. The composite specimens were clamped in the UTM's grippers and subjected to increasing loads until they fractured. The specimens have been subjected to a tensile load development rate of 2 mm/min. The specimens' mean tensile values were recorded for subsequent testing. Composite samples for flexural testing were made utilising the three-point bending method in accordance with the ASTM D790-17 standard [23]. Flexural testing was performed, once again, with the help of computerised UTM at a crosshead speed of 2 mm/min. Three samples of each combination were tested for flexural properties, and the average flexural property values were used in the analysis. The ISO 180:2019 standard [24] was used on the Izod impact testing machine during the impact testing of the hybrid composite specimens. Three specimens of each composition were also evaluated for impact strength values, and the average value was taken during the study.

2.4. Water absorption and thickness swelling behaviours

Hybrid composite specimens were subjected to water absorption and thickness swelling experiments in accordance with ASTM D570-98 [25]. Prior to testing, the composite specimens were cut to have dimensions of 20×20×3 mm and dried in an oven at 50°C, chilled to room temperature, and then instantly weighed to an accuracy of 0.001g using a digital weighing machine. Before the composite specimens were exposed to the groundwater environment, their weight was measured. After 12 hours of exposure, the composite specimens were removed from the water environment, carefully dried with a dry cloth, and then promptly weighed with an accuracy of 0.001 g. Composite specimens were weighed every 12 hours from 12 to 120 hours (5 days) with a 12-hour interval between every measurement. The water absorption was calculated using the difference in weight. At different time intervals, the percentage of weight absorption was calculated using Equation (1) and plotted against the square root of the time of water exposure.

$$W_{ab}(\%) = \frac{W_{tm} - W_0}{W_0} \times 100 \tag{1}$$

The percentage of water absorbed is denoted by W_{ab}, the weight of the composite specimen before and after being exposed to water is denoted by W_0, and W_{tm}, respectively.

Equation (2) was utilised in the process of determining the percentage of thickness swelling (TS (%)):

$$TS(\%) = \frac{H_{tm} - H_0}{H_0} \times 100 \tag{2}$$

Where H_{tm} and H_0 represent the thickness of the composite after and before water exposure, respectively.

2.5. Microscopic images for the cross section of specimens

Figure 3 shows the microscopic images of the cross section of the composite specimens. These images make evident the even distribution of particles throughout the sample and the interfacial bonding between the matrix and fibre.

3. Results and Discussion

3.1. Mechanical properties of composites under dry conditions

3.1.1. Tensile properties

Figures 4a and 4b present an illustration of the results of tensile tests conducted on LCF/GSP/PF hybrid composites with standard error under dry conditions. Both the tensile strength and the modulus of the neat PF sample measured at 28.3 MPa

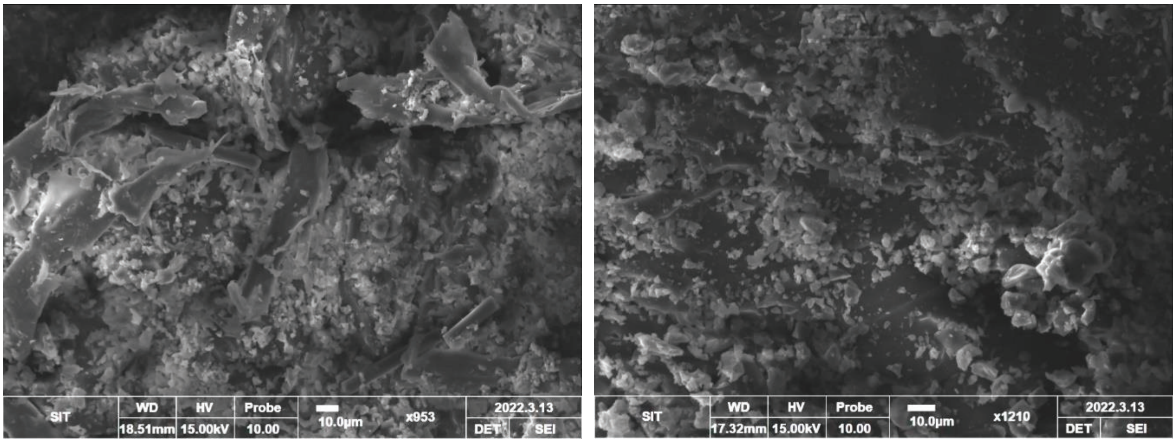
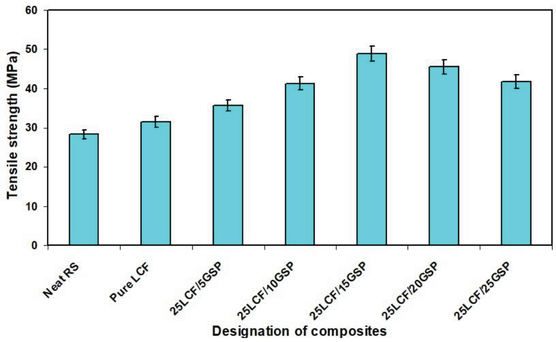
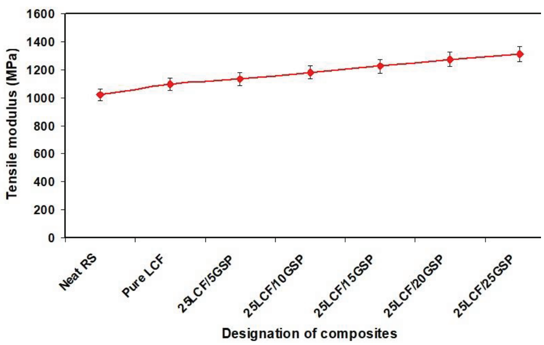


Fig. 3. Typical SEM observations of composite specimens



(a)



(b)

Fig. 4. Tensile properties of LCF/GSP/PF hybrid composites under dry conditions: (a) tensile strength, and (b) tensile modulus

and 1021.7 MPa, respectively. In a similar manner, the tensile strength of the pure LCF/PF composite was 31.5 MPa and the tensile modulus was 1097.5 MPa. Figure 4a indicates that the tensile strength and modulus of LCF/GSP/PE hybrid composites increased from 5wt% to 15 wt% of GSPs, but subsequently decreased with an increase in GSP content (20 wt% and 25 wt%). This can be seen by comparing the results of these two properties before and after increasing the GSP content. The tensile strength of the hybrid composite attained its maximum value of 48.9 MPa when the GSP content was 15 wt% (LCF25/15GSP/PF). Compared to the sample of neat resin and the sample of pure LCF/PF composite, this resulted in an increase corresponding to 72.8% and 55.2%, respectively. When the GSP content was 15 wt%, it was uniformly distributed in the PF matrix with LCFs and successfully encased by it. The fibres were uniformly dispersed and entangled at this point, establishing an interlocking network structure with the PF matrix and LCFs. The resultant structure could withstand an external load, demonstrating that adding 15 wt% GSP to the composites could improve their mechanical properties [26].

When GSPs were included beyond 15% weight, the PF matrix could not wrap the LCFs and GSPs consistently, leaving several LCFs and GSPs exposed. The extent and strength of the interfacial bonds among the matrix, LCFs, and GSPs reduced. Furthermore, because of the high reinforcement content, aggregation occurred easily during the mixing process, resulting in a concentration of stress in the composite materials. Tensile modulus values increased linearly as GSP content increased, as shown in Figure 4b. The tensile modulus of the 25LCF/15GSP composite was 1225.4 MPa, an improvement of 19.94% and 11.65% over the neat resin sample and the pure LCF composite, respectively. The maximum tensile modulus value (1312.6 MPa) was found for the 25LCF/25GSP composite, which improved by 28.5% and 19.6% when compared to the neat resin sample and the pure LCF composite, respectively.

3.1.2. Flexural properties

Figures 5a and 5b depict the flexural properties of LCF/GSP/PF hybrid composite specimens at various GSP weight percentages. The pure LCF composite's flexural strength and modulus were measured to be 36.9 MPa and 1148.4 MPa, respectively. Similarly, the neat resin sample's flexural strength and modulus were 33.4 MPa and 1107.5 MPa, respectively. The incorporation of GSPs with LCFs and PF resin matrix appears to be more effective in improving the flexural properties of the composite. When 15 wt% GSPs were dispersed with the LCFs and the PF resin matrix (i.e., 25LCF/15GSP/PF), the maximum flexural strength was observed to be 56.4 MPa. Flexural strength is increased by 68.86% and 52.85%, respectively, when compared to the neat resin sample and the pure LCF composite. The voids or gaps are due to incomplete resin impregnation during manufacturing, and these voids can weaken the material. Adding of 15 wt% GSPs to LCF/PF composites likely decreased voids, potentially enhancing overall strength and resulting in composites with an improved level of strength. It has a potential that the GSPs served as a link between the LCFs and the PF resin matrix, resulting in enhanced coupling between the fibres and matrix. The stress induced by the applied load may have been easily passed from the PF resin matrix to the LCFs, resulting in an increase in flexural properties.

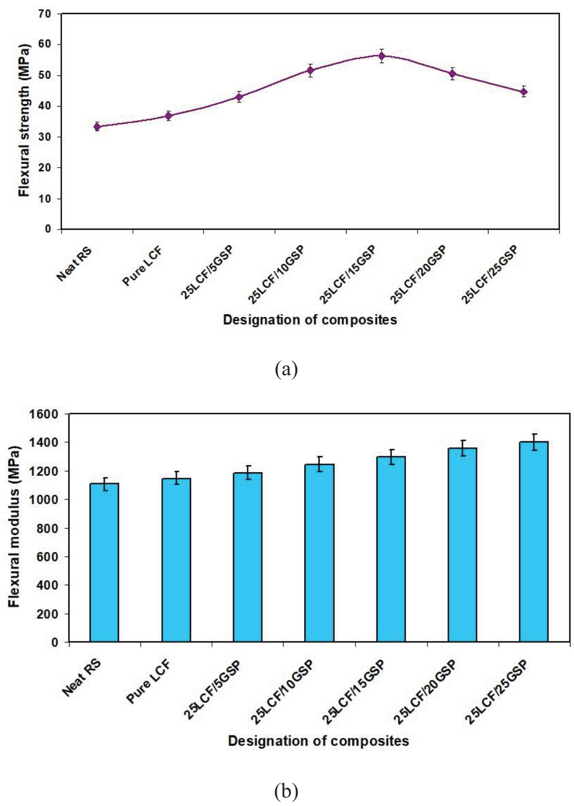


Fig. 5. Flexural properties of LCF/GSP/PF hybrid composites under dry conditions: (a) flexural strength and (b) flexural modulus

The flexural properties of the composite were dramatically improved, however, only after the addition of 15 wt% GSP. The flexural strength of the LCF/GSP/PF hybrid composites was 43.1, 51.7, 56.4, 50.5, and 44.8 MPa, which corresponded to the incorporation of 5, 10, 15, 20, and 25 wt% GSP in the PF resin matrix, as shown in Figure 5a. After 15 wt% GSP inclusion, the flexural strength of the composite began to decrease. This could be because an increase in GSPs creates more molecule-to-molecule contacts rather than causing interactions between the LCFs and the PF resin matrix [27]. In addition, the increase in GSP content may have increased the number of micro voids in the composite material. It may be due to the accumulation of GSPs in the matrix, which may have degraded the adhesive between GSPs and the PF resin matrix, thereby decreasing the composite's flexural properties [24]. In the case of flexural modulus, as in tensile properties, a linear trend was seen in the LCF/GSP/PF composites, as indicated in Figure 5b. The flexural modulus of the 25LCF/15GSP composite was 1297.2 MPa, which is 17.13% greater than that of the neat resin sample and 12.96% higher than that of the pure LCF composite, respectively. The maximum flexural modulus of 25LCF/25GSP composite was 1402.4 MPa, an improvement of 22.12% and 26.63% over

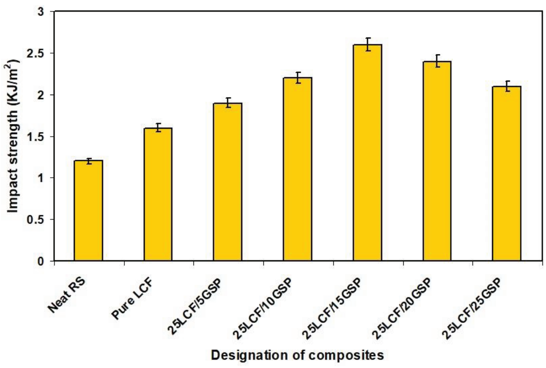


Fig. 6. Impact strength of LCF/GSP/PE hybrid composites under dry conditions

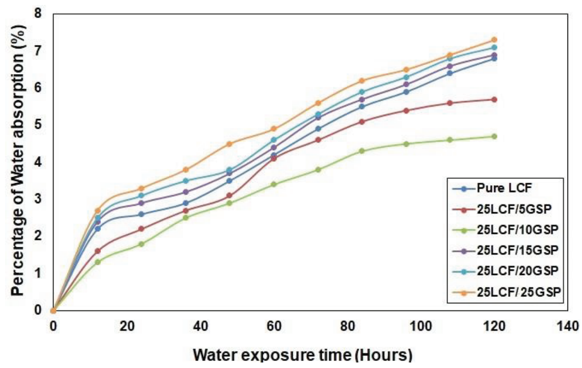


Fig. 7. Water absorption behaviours of LCF/GSP/PF composites based on the exposure time

the neat resin sample and pure LCF composite, respectively.

3.1.3. Impact strength

Figure 6 illustrates the impact strengths of LCF/GSP/PF composites with different GSP concentrations. The neat resin sample has an impact strength of 1.2 KJ/m^2. Furthermore, the impact strength of the pure LCF composite was measured to be 1.6 kJ/m^2. The impact strength of the composite was observed to increase with the inclusion of GSP content until 15 wt% with the LCFs and the PF resin matrix and then starts to decrease as observed in the composites' tensile and flexural strengths. It could be attributed to a decrease in impact strength of the LCF/GSP/PF composites due to weak GSP penetration within the PF resin matrix at greater GSP weight percentages. The maximum impact strength was 2.6 kJ/m^2 at 15% GSPs with LCFs and PF resin matrix, which was 116.7% and 62.5% greater than the neat resin sample and pure LCF composite, respectively.

3.2. Water absorption and thickness swelling behaviours of composites

The reinforcements (natural fibres and particles) derived from biomaterials have a low resistance to water absorption, and as a result, natural fibre and particle-based composites exposed to water have detrimental effects on dimensional stability and mechanical behaviours. The interface between the reinforcements and the matrix as well as the reinforcement itself absorbs the majority of the moisture through hydrogen bonding. To comprehend the durability of composites depending on the field of utilization, the moisture absorption behaviour of natural fibre composites must be studied. As shown in Figure 7, the percentage of water absorption was graphed against the exposure time (hours). Figure 7 demonstrates that the water absorption of LCF/GSP/PE hybrid composites increased linearly during exposure to water. The 25LCF/25GSP hybrid composite exhibited the highest water absorption rate of 4.3%, followed by the 25LCF/20GSP and 25LCF/15GSP composites. This difference in water absorption percentage between the 25LCF/15GSP and 25LCF/25GSP hybrid composites is attributable to the reinforcement weight percentage and chemical composition, i.e., cellulose content. As a consequence of increased contact between water molecules and reinforcements, the water absorption of composites increased with an increase in reinforcement content [28]. With increasing exposure time, the percentage of water absorption increased. It reveals that bio-based natural fibres and particle-reinforced composites absorb water particles on a continuous basis [29].

The percentage of water particles absorbed by 25LCF/15GSP, 25LCF/20GSP, and 25LCF/25GSP hybrid composites is likewise less than that of the 25LCF/10GSP hybrid composite. It could be attributed to an increase in cellulose content from the addition of more GSPs to the LCF/PE composite. It may also be due to the hydrophilic nature of the LCFs and GSPs. Furthermore, the

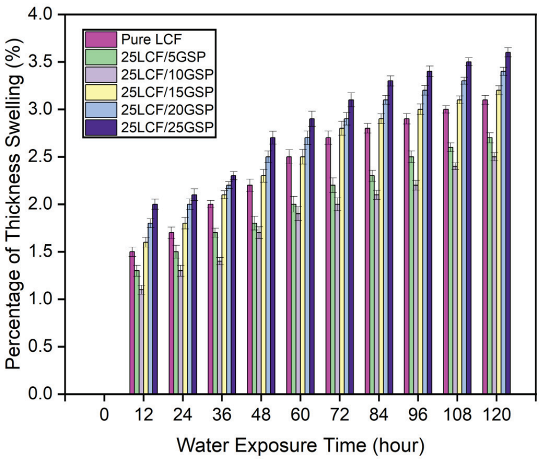


Fig. 8. Thickness swelling behaviours of LCF/GSP/PF composites based on the exposure time

proportion of water particles absorbed by the hybrid 25LCF/10GSP composite was lower than that of the pure LCF composite. It was discovered that combining certain amounts of GSPs with LCFs in PF decreases the water absorption behaviour of the composite to some level. In addition to a certain amount of GSPs, the further addition increases the water absorption behaviour of the composites due to higher cellulose content in the composites [26].

The thickness swelling behaviour of LCF/GSP/PF hybrid composites is depicted in Figure 8. The thickness swelling of composite specimens was seen to rise with increasing water exposure times and reinforcing content. The 25LCF/10GSP hybrid composite had decreased thickness swelling behaviour, according to the results. This could be due to the hybridization effect, in which the GSPs reduced water particle absorbance and hence prevented composite swelling. Furthermore, GSPs have a lower cellulose concentration than LCFs. Although the insertion of groundnut shell particles limits water particle absorbance, increasing the amount of GSPs with the LCFs increases the percentage of water absorption and thickness swelling as a result of the presence of cellulose [26]. As a result, the 25LCF/25GSP hybrid composite (1.67%) exhibits greater thickness swelling behaviour. The results showed that the hybrid composite with 25 wt% LCFs and 10 wt% GSPs exhibited decreased water absorption and swelling.

3.3. Mechanical properties of composites after water uptake

3.3.1. Tensile properties

After the water absorption study, the composite specimens were used to evaluate mechanical properties. The variations in mechanical properties of LCF/GSP/PF hybrid composites were presented based on the weight percentage of GSPs. Figure 9 depicts the changes in tensile strength and modulus of LCF/GSP/PF composites after water immersion. The tensile strength and modulus of the pure LCF/PF composite were 23.5 MPa and 912.5 MPa, respectively. Tensile strength and modulus trends of composites after water immersion differed from those before water immersion. As under dry conditions, however, the tensile strength of the composite increased up to the inclusion of 15 wt% GSPs and subsequently decreased. The tensile strength of LCF/GSP/PF composites reduced to some extent after water immersion compared to before water immersion. The tensile strength of the 25LCF/15GSP composite, however, was higher than that of the other composites. It represented a reduction of 24.13% when compared to the same composites prior to water immersion. This may be because the weight percentage of GSPs increased when water absorption and bonding to the PF resin matrix were reduced. The surface compatibility and interfacial adhesion decreased, decreasing the tensile strength of the composite [32]. Moreover, the 25LCF/15GSP composite experienced a lesser

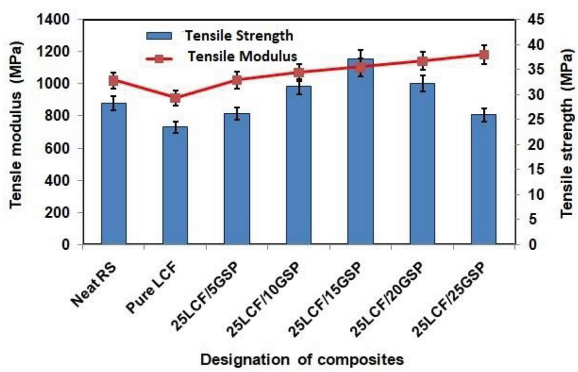


Fig. 9. Tensile properties of the LCF/GSP/PF hybrid composites under wet conditions

reduction in tensile strength under wet conditions than the other composites. In comparison to the pure LCF composite, the 25LCF/15GSP composite exhibits a 57.9% increase in tensile strength. It indicated that the adhesion between LCFs, GSPs, and PF was stronger and that the interfacial properties of composites were enhanced. The values of tensile strength were very close to being the same for both the 25LCF/5GSP and the 25LCF/25GSP composites (see Fig. 9), as well as for the 25LCF/10GSP and the 25LCF/20GSP composites. Similarly to dry conditions, the tensile modulus of composites increased with increasing GSP content up to 25 wt%, as presented in Figure 9. The 25LCF/25GSP composite has a maximum tensile modulus of 1183.5 MPa, which is a 29.7% improvement over the pure LCF composite after water immersion.

3.3.2. Flexural properties

Figure 10 depicts the flexural properties of the LCF/GSP/PF hybrid composites after water immersion. The flexural strength and modulus of the pure LCF composite were 28.2 MPa and 1097.8 MPa, respectively. The flexural strength of the LCF/GSP/PF composite specimens was 35.7, 42.3, 48.9, 41.8, and 35.1 MPa at 5, 10, 15, 20, and 25 wt% GSPs, respectively. The flexural strength of the composites increased up to 15% of GSPs, after which it dropped. Furthermore, the flexural strength values of composite specimens after water immersion are lower than those of composite specimens under dry conditions. It was initiated by the swelling of the LCFs and GSPs induced by water particle penetration at the interfacial region between the LCFs, GSPs, and the PF resin matrix. As a result, gaps formed between the reinforcements and the resin matrix, causing the reinforcements to de-bond from the matrix. The presence of water particles in the LCFs and GSPs causes them to deteriorate. As a result, the flexural strength of the composites was reduced when wet. The highest flexural strength (48.9 MPa) value was reached at 25LCF/15GSP composite after water immersion, which is 13.3% lower than the 25LCF/15GSP composite under dry conditions. When compared to the pure LCF composite, the 25LCF/15GSP composite shows a 73.4% improvement. Beyond 15 wt% GSPs, the flexural strength of the composite decreased because of an increase in the percentage of water absorption, which may lead to the formation of a greater number of micro cracks as a result of reinforcement swelling, which weakens the reinforcement–matrix interface region when loads are applied [33]. Flexural strength values were almost identical between the 25LCF/5GSP and 25LCF/25GSP composites, as well as the 25LCF/10GSP and 25LCF/20GSP composites (Fig. 10). Moreover, as demonstrated in Figure 10, the flexural modulus of the LCF/GSP/PF composites increased as the GSP content increased. The flexural modulus of the 25LCF/15GSP composite is 1218.6 MPa, which represents a 6.8% drop when compared to the same composite under dry conditions. The greatest flexural modulus was observed at the 25LCF/25GSP water-absorbed composite and which is 10.1% higher than the pure LCF composite.

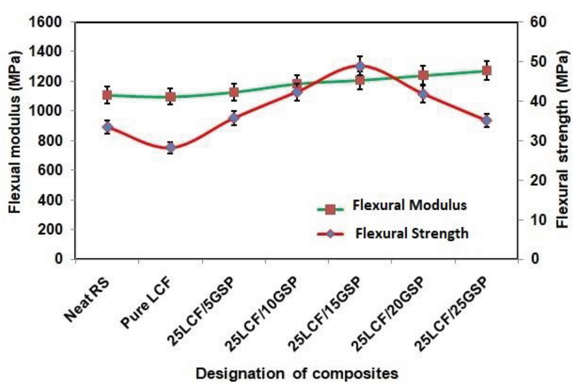


Fig. 10. Flexural properties of LCF/GSP/PF hybrid composites under wet conditions

3.3.3. Impact strength

Figure 11 shows the impact strength of the LCF/GSP/PF hybrid composites after water immersion. The pure LCF composite has an impact strength of 1.2 KJ/m^2. The impact strength of moisturized composite specimens was less than that of dry composite specimens. It could be due to water particle scattering into the interface region causing weak interfacial bonding between the reinforcements and the resin matrix.

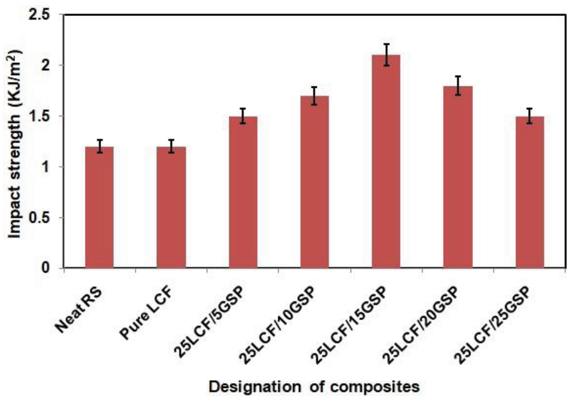


Fig. 11. Impact strength of the LCF/GSP/PF hybrid composites under wet conditions

Table 1. Comparison between some mechanical and physical properties of the developed green composite with DPL-reinforced composite

Properties	**Developed green material Ref. 25LCF/15GSP**	**DPL-reinforced composite [30]**
Average tensile strength	Mean of 52 MPA	Ranged between 48 and 62.6 MPa
Tensile modulus	Mean of 1200 MPA	Max 1180 MPA
Flexural strength	Mean of 60 MPa (2 mm/min)	Max 52 MPa (at 5 mm/min loading speed)
Water absorption	Up to 3.3% after 120 H	Up to 5.8%

The impact strength increased as GSPs content increased up to 15wt.% and thereafter decreased as shown in Figure 11. When compared to the impact strength of 25LCF/15GSP composite under dry conditions, the impact strength of 25LCF/15GSP moisturized composite is reduced by 19.2%. The 25LCF/25GSP and 25LCF/5GSP composites show the same level of impact strength. When compared to the pure LCF composite, the 25LCF/15GSP composite improves by 75% after water immersion.

The properties of a material are contingent upon the percentage of reinforcements incorporated. As such, the outcomes exhibit variability. An optimal strength or performance is achieved when 15% of additives are utilized. Beyond this threshold, an increase in particle content enhances density but also imparts a brittle quality to the material. Consequently, the material experiences a loss in strength when the particle concentration exceeds 15%.

4. Comparison of the properties of developed hybrid composites with existing composites

To highlight the ability of the fibres and particles studied to improve the performance of green composite materials, a comparative study between the mechanical and physical properties of the newly developed green materials with date palm leaf-reinforced composite was established, based on the references. Table 1 shows the chosen properties to compare. It is important to clarify that the reference DPL composite material was made from 40 wt% green fibre + phenolic resin with an average of 12–15 mm fibre length. This choice corresponds to the same green added elements to formulate 25LCF/15GSP composite materials. Therefore, for the same weight, and approximate range of green reinforcement elements, the developed materials presented comparable mechanical properties in terms of tensile strength and modulus. A more noteworthy flexural strength was noticed for the developed materials. These results can be attributed to the slight differences inloading speed, which is more important for the DPL-reinforced composite. For the water absorption properties, the ability of DPL-reinforced composite was more important. This characteristic can be attributed to the anatomy of the date palm leaf, which accelerates and facilitates the water absorption [33, 34].

5. Conclusion

The LCF/GSP/PF hybrid composites have been produced by varying the content of GSPs using the hand lay-up method. The mechanical properties of LCF/GSP/PF composites were determined using the GSP weight percentage. By immersing the composite specimens in water for 5 days, the water absorption and thickness swelling behaviours of

LCF/GSP/PF composites were examined. Furthermore, the mechanical properties of wet composites were investigated and compared to dry composites. The inclusion of GSPs increases the tensile strength of the composite up to 15 wt% under dry conditions, after which it decreases. When the GSPs increased, however, the tensile modulus of composites increased linearly. The flexural properties followed the same pattern as the tensile properties. Impact strength values increased up to 15% of GSPs and then decreased. The percentage of the water absorption and thickness swelling of the composites increases with the increase in weight percentage of the reinforcements as a result of the amount of cellulose content. The mechanical properties of composite specimens under wet conditions are lower than those of composite specimens under dry conditions. The tensile, flexural, and impact strength values, however, were increased up to 15 wt% of GSPs and further addition of GSPs decreases the strength values under wet conditions. Under wet conditions also, the 25LCF/15GSP composites showed the maximum strength values. It can be concluded from the present study that a composite with 25 wt% of LCFs and 15 wt% of GSPs can be used for the products of commercial applications. Because of the cellulose component, the percentage of water absorption and thickness swelling of the composites increases as the weight percentage of the reinforcements increases. Compared to the DPL composite material, their mechanical and physical properties were more remarkable, especially in flexural strength. Composite specimens under wet conditions have lower mechanical properties than composite specimens under dry conditions. However, the tensile, flexural, and impact strength values of GSPs have been increased up to 15 wt%, and further GSP addition reduces the strength values under wet conditions. The 25LCF/15GSP composites likewise had the highest strength ratings when wet. According to the results of this investigation, a composite containing 25% LCFs and 15% GSPs can be employed for commercial applications. These material properties open the horizon to the use of these developed materials in several engineering solutions, particularly eco-friendly friction materials for braking systems.

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References

[1] Nabi Saheb D, Jog JP. Natural fiber polymer composites: a review. *Adv Poly Technol*. 1999;18(4):351–63.

[2] Sinha AK, Narang HK, Bhattacharya S. Mechanical properties of natural fiber polymer composites. J Polym Eng. 2017;37(9):879–95.

[3] Khalid MY, Rashid AA, Arif ZU, Ahmed W, Arshad H, Zaidi AA. Natural fiber reinforced composites: sustainable materials for emerging applications. *Results Eng*. 2021;11:100263.

[4] Chen Y, Su N, Zhang K, Zhu S, Zhu Z, Qin W, et al. Effect of fiber surface treatment on structure, moisture absorption and mechanical properties of Luffa sponge fiber bundles. *Ind. Crop. Prod*. 2018;123:341–52,

[5] Boynard CA, Monteiro SN, d'Almeida JRM. Aspects of alkali treatment of sponge gourd (*Luffa cylindrica*) fibers on the flexural properties of polyester matrix composites. *J Appl Polym Sci.* 2003;87(12):1927–32. doi: 10.1002/app.11522

[6] Ghali L, Msahli S, Zidi M, Sakli F. Effects of fiber weight ratio, structure and fiber modification onto flexural properties of Luffa-polyester composites. *Adv Mater Phys Chem.* 2011;1(3):78.

[7] Shen J, Xie YM, Huang X, Zhou S, Ruan D. Mechanical properties of Luffa sponge. *J Mech Behav Biomed Mater*. 2012;15:141–52. doi: 10.1016/j.jmbbm.2012.07.004

[8] Mohanta N, Acharya SK. Tensile, flexural and interlaminar shear properties of Luffa cylindrica fiber reinforced epoxy composites. *Int J Macromol Sci*. 2013;3:6–10.

[9] Mohanta N, Acharya SK. Mechanical and tribological performance of *Luffa cylindrica* fiber-reinforced epoxy composite. *BioRes*. 2015;10(4):8364–77.

[10] Satishkumar N, Purushothaman N, Raghuram P. An investigation on *Luffa cylindrica* fiber reinforced epoxy composite. *Mater Today: Proc*. 2020;33(1):1026–31.

[11] Mehra AK, Saini R, Kumar A. The effect of fiber contents on mechanical and moisture absorption properties of gourd sponge/coir fiber reinforced epoxy hybrid composites, *Compos Commun*. 2021;25:100732.

[12] Raveendran K, Ganesh A, Khilart KC. Influence of mineral matter on biomass pyrolysis characteristics. *J Fuel*. 1995;74:1812–22.

[13] Raju GU, Kumarappa S. Experimental study on mechanical properties of groundnut shell particle-reinforced

epoxy composites. *J Reinforc Plast Compos*. 2011; 30(12):1029–37.
[14] Gumel SM, Adam JL, Habibu S. Tensile properties of treated and untreated groundnut shell filled natural rubber composites. *J Appl Chem*. 2014;7(10):40–44.
[15] Adeosun S, Taiwo O, Akpan E, Gbenebor O, Gbagba S, Olaleye S. Mechanical characteristics of groundnut shell particle reinforced polylactidenano fiber. *Rev Mater*. 2016;21(2):482–91.
[16] Usman MA, Momohjimoh I, Gimba ASB. Effect of groundnut shell powder on the mechanical properties of recycled polyethylene and its biodegradability. *JM MCE*. 2016;4:228–40.
[17] Kisan U, Dubey V, Kumar Sharma A, Mital A. Synthesis of groundnut shell/rice husk hybrid composite–a review. *IOP Conf. Ser Mater Sci Eng*. 20221;1116(012001): 1–16.
[18] Potadar OV, Kadam GS. Preparation and testing of composites using waste groundnut shells and coir fibers. *Procedia Manuf*. 2018;20:91–6.
[19] Nyior GB, Aye SA, Tile SE. Study of mechanical properties of raffia palm fiber/groundnut shell reinforced epoxy hybrid composites. *JMMC E*. 2018;6:179–92.
[20] Adeosun S, Taiwo O, Akpan E, Gbenebor O, Gbagba S, Olaleye S. Mechanical characteristics of groundnut shell particle reinforced polylactide nano fibre. *Matéria* (rio De Janeiro). 2016;21(2):482–91. doi: 10.1590/S1517-707620160002.0045
[21] Sathiparan N, Anburuvel A, Selvam VV. Utilization of agro-waste groundnut shell and its derivatives in sustainable construction and building materials – a review. *J Build Eng*. 2023;66:105866. ISSN 2352-7102. doi: 10.1016/j.jobe.2023.105866
[22] ASTM D638-14, Standard Test Method for Tensile Properties of Plastics. ASTM International, West Conshohocken. 2014;1–17.
[23] ASTM D790-17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM International, West Conshohocken. 2017;1–12.
[24] ISO 180:2019, Plastics – Determination of Izod impact strength. 2019;1–13.
[25] ASTM D570-98, Standard Test for Water Absorption of Plastics. 2018;1–4.
[26] Sapiai N, Jumahat A, Jawaid M, Midani M, Khan M. Tensile and flexural properties of silica nanoparticles modified unidirectional kenaf and hybrid glass/kenaf epoxy composites. *Polymers*. 2020;12(11):2733.
[27] Ashok KG, Kalaichelvan K, Damodaran A. Effect of nano fillers on mechanical properties of luffa fiber epoxy composites. *J Nat Fibers*. 2022;19(4):1472–89.
[28] Muñoz E, García-Manrique JA. Water absorption behaviour and its effect on the mechanical properties of flax fiber reinforced bioepoxy composites. *Int J Polym Sci*. 2015;2015:1–10.
[29] Haameem MJA, Abdul Majida MS, Afendi M, Marzukib HFA, Ahmad Hilmib E, Fahmia I, Gibson AG. Effects of water absorption on Napier grass fibre/polyester composites. *Compos Struct*. 2016;144: 138–146.
[30] Espert A, Vilaplana F, Karlsson S. Comparison of water absorption in natural cellulosic fibers from wood and one-year crops in polypropylene composites and its influence on their mechanical properties. *Compos Part A Appl Sci Manuf*. 2004;35:1267–76.
[31] Bollino F, Giannella V, Armentani E, Sepe R. Mechanical behavior of chemically-treated hemp fibers reinforced composites subjected to moisture absorption. *J Mater Res Technol*. 2023;22:762–75.
[32] Al-Sulaiman FA. Mechanical properties of date palm fiber reinforced composites. *Appl Compos Mater*. 2002;9:369–77. doi: 10.1023/A:1020216906846
[33] Sreekala MS, Kumaran MG, Thomas S. Water sorption in oil palm fiber reinforced phenol formaldehyde composites. *Compos Part A Appl Sci Manuf*. 2002;33(6): 763–77.
[34] Sanjeevi S, Shanmugam V, Kumar S, et al. Effects of water absorption on the mechanical properties of hybrid natural fiber/phenol formaldehyde composites. *Sci Rep*. 2021;11:13385. doi: 10.1038/s41598-021-92457-9

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