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Influence of Moisture Absorption on some Mechanical Properties of Groundnut Shell Powder Reinforced Waste LDPE Composites

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Abstract: *The effect of water absorption on the mechanical properties of groundnut shell powder (GSP) filled waste low-density polyethylene (wLDPE) has been investigated. The composite samples were developed via melt mixing and compression moulding techniques respectively. The percentage weight fraction of the reinforcement was varied from 4-20 % wt (4, 8, 12, 16 and 20 % wt) respectively. Incorporation of GSP into wLDPE was observed to improve the tensile, flexural and impact strength of the material; which was observed to increase with the amount of treated GSP incorporated. However, immersion of the composites samples in water for a period of 720 hours led to degradation of the fibre-matrix interface and created poor stress transfer efficiencies resulting in the reduction of tensile strength, elastic modulus, flexural strength, impact energy while increment in % elongation and flexural modulus were recorded. This indicates that the mechanical properties of GSP reinforced waste LDPE could be adversely affected by long-term exposure to moisture absorption.*

Keywords: *Groundnut shell powder, mechanical properties, moisture absorption, waste low-density polyethylene, wastewater sachets*

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1.0 Introduction

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by conventional metals, alloys, ceramics, and polymeric materials. This is why the interest of scientists and engineers has turned to composite materials that provide better property combinations and result in significantly different physical, mechanical and thermal properties (Jacob, 2019). Natural fibres are exploited as a replacement for conventional fibers such as glass, aramid and carbon due to their advantages such as low cost, availability, high-strength to weight ratio and fairly good mechanical properties. Groundnut shell is an agricultural waste that is in abundance in most Northern States of Nigeria, and there is no reported use of this waste for the benefit of mankind in these areas, hence the need to explore it, as a source of inexpensive fillers in composite production.

Several researchers have reported the use of groundnut shell powder in the development of composite materials and are thus summarized: The effect of groundnut shell powder on the viscoelastic properties of recycled high-density polyethylene composites was investigated by Jacob *et al.* (2018a); the results showed that incorporation of groundnut shell powder in waste HDPE improved its thermal stability.

Jacob *et al.* (2019a) also studied the thermo-mechanical characterization of plantain particulate reinforced waste HDPE as composite wall titles. The results showed that the composite materials have improved mechanical and thermal properties. Mechanical properties and water absorption characteristics of composites reinforced with cotton fibres recovered from textile waste were studied by Kamble and Behera (2020). Similarly, Jacob and Mamza (2020) also reported the mechanism of water absorption behavior in groundnut shell waste HDPE composites and observed that long term moisture absorption affects the interfacial adhesion between the polymer matrix and the fibre. The mechanical and thermal behavior of plantain peel powder-filled recycled polyethylene composites has also been investigated Jacob and Mamza (2021). The results indicated that incorporation of treated plantain peel powder and *kankara* clay into waste LDPE enhanced its mechanical, thermal creep resistance behavior. The poor resistance of natural fibres such as groundnut shell powder to water absorption can have undesirable effects on the physico-mechanical and thermal properties of the composites. It has become pertinent therefore to carry out more research on the influence of water absorption on the physical and mechanical properties GSP reinforced waste low density polyethylene to explore it as a suitable reinforcement in composite production.

2.0 Materials and Method

2.1 Sample collection and material preparation

Wastewater sachets made from low density polyethylene were collected from refuse dumps. These samples were thoroughly washed with water, dried and shredded into particles of smaller sizes that constitute the polymer matrix (Jacob and Mamza, 2021). The groundnut shell powder used as reinforcement was also sourced locally, sun-dried, pulverized and sieved to 100 μm.

To reduce potential surface hindrances and bring about better adhesion between hydrophilic GSP and hydrophobic polymer matrix, the groundnut shell powder was initially treated with 5 % NaOH solution for six hours, stirred and filtered. It was then rinsed with distilled water until the solution becomes neutral. The alkaline pre-treated sample was then suspended in benzoyl chloride solution for 15 minutes. The isolated fibres were then soaked in ethanol for 1 hour to remove the benzoyl chloride and finally washed with distilled water and dried in an oven at 80 ^{0}C for 24 hours (Jacob *et al.*, 2018b; Jacob *et al.*, 2019b).

2.2 Composite production

The GSP reinforced waste LDPE composite samples were produced by the compounding process achieved by the addition of the shredded waste LDPE at a temperature of 150 ℃ using the procedure earlier described by (Jacob *et al.*, 2018b; Jacob and Mamza, 2021). The percentage fibre loading was varied from 0-20 % (0, 4, 8, 12, 16 and 20 %) respectively. The 0%, in this case, serves as the control sample.

2.3 Mechanical properties test

2.3.1 Tensile test

The tensile test was performed using Instron universal tester 3369 model according to ASTM D638 (2014) standard at the Engineering Materials Development Institute, Akure, Ondo State, Nigeria. Sample specimen dimensions of 115 x 19 x 5mm were produced for the test. The dumbbell part was clamped to the jaws of the machine and the extension was produced within the gauge span of the specimen. Tensile characteristics such as elastic modulus, tensile strength, elongation at break and stress versus strain curve were automatically determined from the PC-based testing software (Jacob, 2019).

2.3.2 Flexural strength

Flexural strength is the ability of the composite to withstand bending. Flexural strength was determined according to ASTM D790 (2015) using a universal (digital) flexural testing machine (EnerPac-P-391). Sample specimen dimensions of 60 x 10 x 5mm were produced for the test. The test sample was placed between two rollers and force (hydraulic handle) was applied until the sample ruptured. The flexural strength (MPa) and flexural modulus (MPa) were calculated using equations (1) and (2) respectively.

$$\sigma = \frac{3PI}{2bt^2} \qquad (1)$$

$$E = \frac{PL^3}{4bd^3D} \qquad (2)$$

where; l = length of specimen span between support (mm), P = maximum deflection force (N), b is the width of the specimen (mm),t is the thickness of specimen (mm), D is the deflection (mm), σ is the flexural strength, and E is the flexural modulus.

2.3.3 Impact energy test

The reliability of a material can be determined by measuring its resistance to fracture, either ductile or brittle and fracture toughness. The impact test on the developed composite samples was carried out using a fully instrumented Charpy impact testing CAT NR412 model according to ASTM F2231-02 (2013). The dimensions, gauge length and V-notch were chosen according to the standard. The specimen was placed between a sample holder with the notch oriented vertically and towards the origin of the impact. The specimen was struck by a "tup" attached to a swinging pendulum. The specimen breaks at its notched cross-section upon impact, and the upward swing of the pendulum was used to determine the amount of energy absorbed in the process and the results were recorded in Joules (J) (Jacob, 2019).

2.4 Water absorption

The water absorption test was carried out according to ASTM D570 (2010) method. The test sample of dimension 76 × 25 × 5 mm was initially dried in an oven and then immersed in water at room temperature for 24 hours. After an immersion period of 24 hours, the specimens were removed and cleaned with a lint-free dry cloth and then reweighed using a Sartorius ED 224S digital Analytical balance. To evaluate long term moisture absorption on the composites, the process was repeated at 48, 72, 96, up to 720 hours of exposure. The weight of the dried specimen ($W_{initial}$) and weight after immersion (W_{final}) were recorded (Jacob and Mamza, 2021). The amount of water absorbed was determined as follows:

$$W = \frac{W_{final} - W_{initial}}{W_{final}}(\%) \qquad (3)$$

3.0 Results and Discussion

3.1 Effect of moisture absorption on the tensile strength of GSP-wLDPE composites

The ultimate tensile strength as a function of the weight fraction of reinforcement results for GSP-wLDPE samples (exposure time up to 24 h at 27 ℃) is shown in Fig.. 1. It is interesting to note that there was a significant increase in tensile strength at 4% weight fraction of reinforcement by 38.4% after immersion in water. This increase in tensile strength for 4wt% PPP reinforced sample implies that further cross-linking or other mechanisms have taken place enhancing the material strength. The tensile strength, however, drops by 24.3%, 32.9%, 22.8%, and 23.0%, respectively, for 8 wt%, 12 wt%, and 16 wt% and 20 wt% PPP reinforced specimens. A similar result has been reported by other authors (Jacob and Mamza, 2020). Generally, for composites with a higher weight fraction of reinforcement immersed in water, it is expected that the relative extent of decrease in tensile properties is greater compared to dry samples. This could be because high amounts of water cause swelling of the fibres, which could fill the gaps between the fibre and the polymer matrix and eventually lead to a decrease in the mechanical properties of the composites (Dhakal *et al*., 2006).

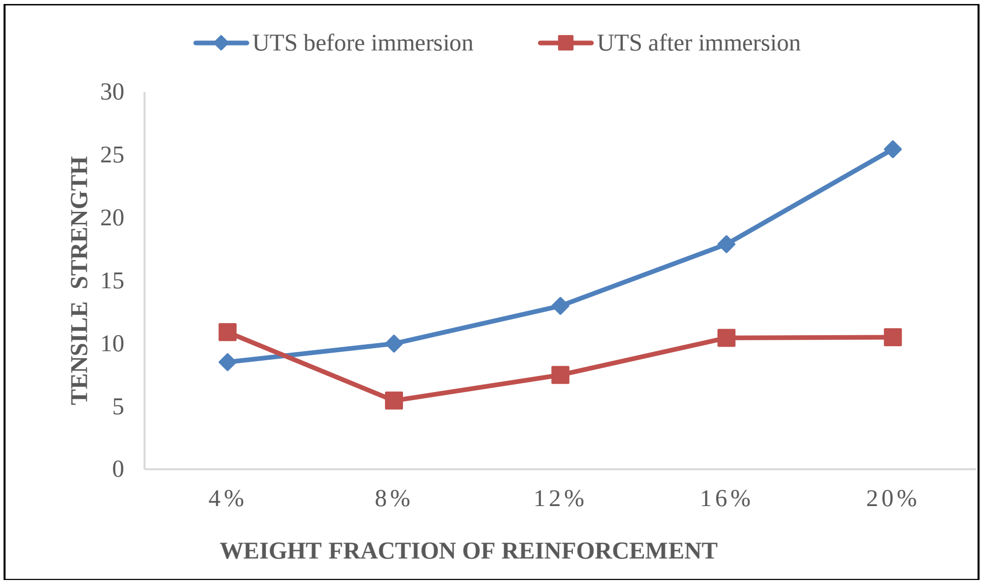

Fig. 1: Effect of water absorption on the tensile strength of GSP-wLDPE composites

3.2 Effect of moisture absorption on the flexural strength of GSP-wLDPE composites

The flexural strength as a function of weight fraction of reinforcement for dry and water immersed (exposure time 240 h at 27 ℃) GSP-wLDPE composites are shown in fig. 2. The flexural strength drops as the weight fraction of reinforcement increases. The decrease in flexural strength after water immersion can be related to the weak fibre-matrix interface due to water absorption. This is at par with observation reported by other authors (Dhakal *et al*., 2006; Alomayri *et al*., 2014).

3.4 Effect of moisture absorption on the % elongation of GSP-wLDPE composites

Fig. 3 displays the failure tensile strain (% elongation at break) values for both the dry composites and water-immersed specimens.

An increase in % elongation at break could be observed after immersion in water. The increase in failure strain upon exposure of the samples to a wet environment can be attributed to the plasticization of PPP samples caused by moisture absorption (Dhakal *et al*., 2006).

3.5 Effect of moisture absorption on the impact energy of GSP-wLDPE composites

Impact strength of fibre-reinforced polymer is governed by the matrix-fibre interfacial bonding, and properties of both matrix and fibre. When the composites undergo a sudden force, the impact energy is dissipated by the combination of fibre pullouts, fibre fracture and matrix deformation (Jacob, 2019).

The effect of fibre contents on the impact strength of dry and wet GSP reinforced wLDPE composites are shown in Fig. 4. It can be seen that impact strength significantly increased as GSP content increased in dry composites from 4% wt to 20% wt. The presence of GSP in the matrix increases the ability of these composites to absorb impact energy. In dry conditions, the addition of GSP with contents of 4, 8 12, 16, and 20 %wt increases the impact strength from 1.80 to 2.56, 3.67 and 3.45J/mm^2, respectively, compared to unreinforced wLDPE. A similar remarkable improvement in impact strength was reported by Alomayri *et al*. (2014).

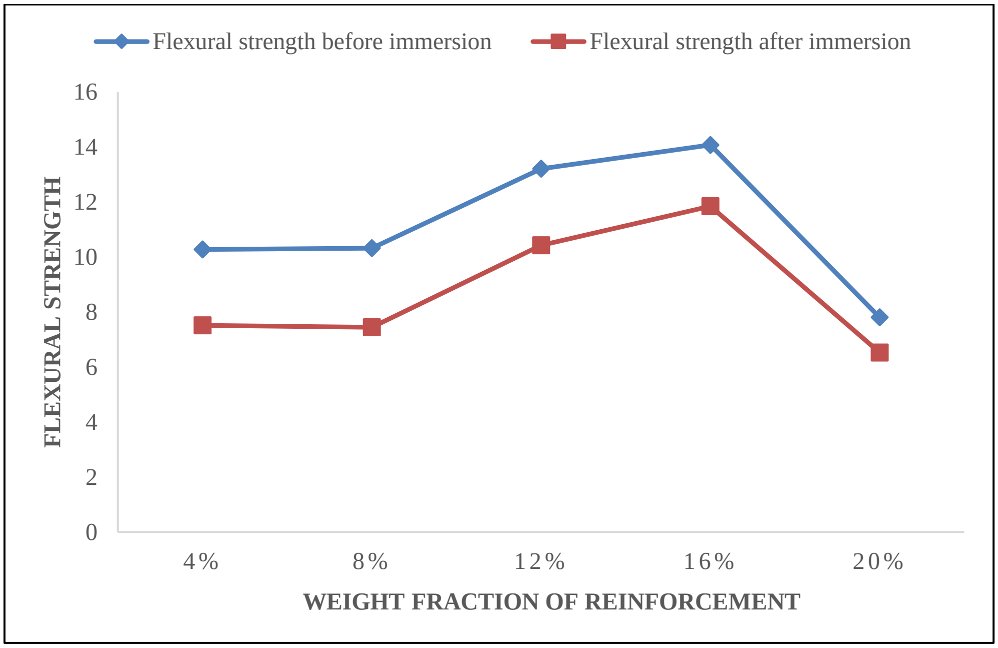

Fig. 2: Effect of moisture absorption on the flexural strength of GSP-wLDPE composites

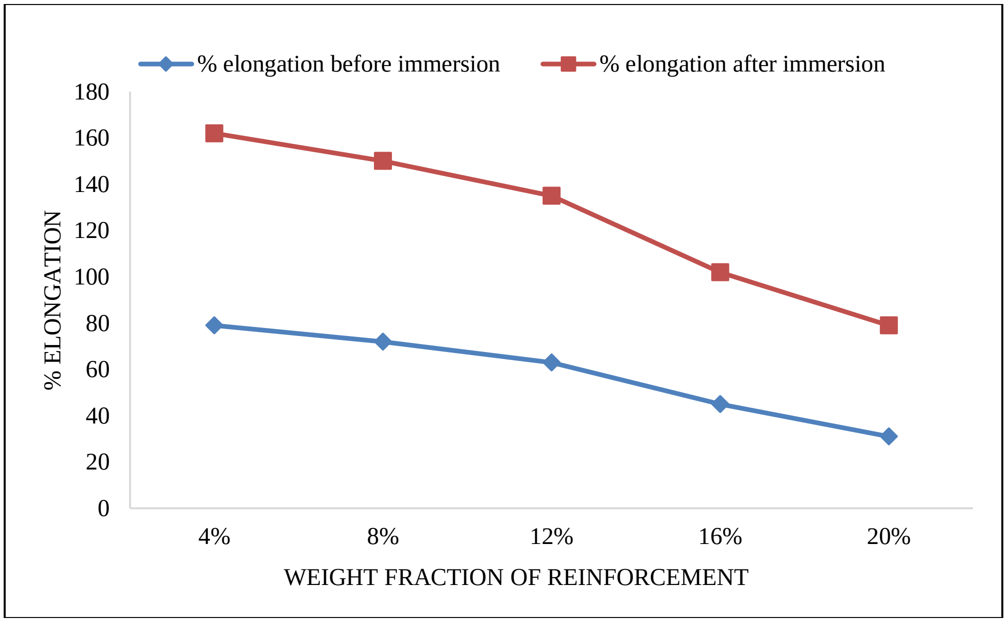

Fig. 3: Effect of moisture absorption on the % elongation of GSP-wLDPE

However, impact strength was adversely affected by water absorption as can be seen in Fig. 4. The decrease in impact properties after water immersion can be related to the weak fibre-matrix interface, which resulted in a reduction of the mechanical properties and dimensional stability of composites.

Table 1 presents results of tensile and flexural modulus for both dry and water-immersed specimens at RT. It could be observed that moisture absorption causes change in the modulus as determined by tensile and flexural tests. The tensile modulus decreases for all PPP reinforced samples. The reduction in tensile modulus for 4%wt-20%wt GSP-wLDPE specimens compared to dry specimens are 50.15%, 64.21%, 67.35%, 71.05% and 78.28% respectively. A plausible explanation for this would be that the elastic modulus is a fibre sensitive property in composites and is affected by moisture absorption.

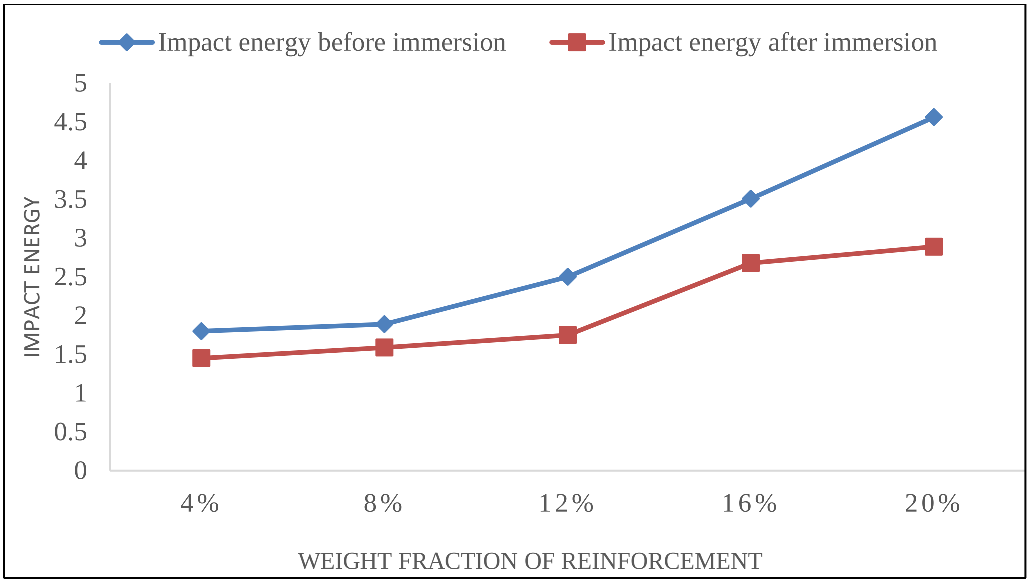

Fig. 4: Effect of moisture absorption on the impact energy of GSP-wLDPE composites

3.5 Effect of moisture absorption on the tensile and flexural modulus

This effect is particularly greater for composites with higher fibre content, in which stress transfer capability between fibre and matrix interface gets sharply reduced due to moisture content. Similar observations have been reported by other authors Alomayri *et al.*, 2014).

The flexural modulus, however, is not adversely affected by moisture absorption. The increase in flexural modulus is more pronounced with higher fibre content specimens and hence higher moisture content.

Table 1: Elastic and flexural modulus for dry and wet GSP-wLDPE samples

Weight of fibre (%)	Elastic modulus (MPa)		Flexural modulus (MPa)	
	Dry	**Wet**	**Dry**	**Wet**
4	45.50	40.15	118.19	130.21
8	50.42	45.21	125.60	137.50
12	60.45	58.50	135.61	148.65
16	75.11	71.05	150.15	177.11
20	70.70	65.20	167.77	188.44

It would be intuitive to assume that the effect of fibre reinforcement is less critical for the flexural failure stress than in the tensile failure mode. This is because the flexural samples fail in the combination of compression, shear and tension mode (Dhakal *et al.*, 2006).

Plate 1: LDPE waste used in the study

4.0 Conclusion

From the results and findings of this work, the following conclusions are made:

(i) The incorporation of treated GSP improved the mechanical properties of waste LDPE.

- The mechanical properties of waste LDPE increased with weight fraction of reinforcement (GSP) from 4 %wt to 20 % wt.
- Except the flexural modulus and % elongation; all the mechanical properties studied were observed to be adversely affected by long term moisture absorption.

5.0 References

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Conflict of Interest

The authors declared no conflict of interest