Journal of Minerals and Materials Characterization and Engineering, 2018, 6, 179-192
http://www.scirp.org/journal/jmmce
ISSN Online: 2327-4085
ISSN Print: 2327-4077

Study of Mechanical Properties of Raffia Palm Fibre/Groundnut Shell Reinforced Epoxy Hybrid Composites

Geoffrey Bem Nyior, Sylvester Aondolumun Aye, Sesugh Emmanuel Tile

Department of Mechanical Engineering, University of Agriculture, Makurdi, Nigeria
Email: sesughtile@gmail.com

How to cite this paper: Nyior, G.B., Aye, S.A. and Tile, S.E. (2018) Study of Mechanical Properties of Raffia Palm Fibre/Groundnut Shell Reinforced Epoxy Hybrid Composites. *Journal of Minerals and Materials Characterization and Engineering*, **6**, 179-192.
https://doi.org/10.4236/jmmce.2018.62013

Received: June 14, 2017
Accepted: March 6, 2018
Published: March 9, 2018

Abstract

The mechanical properties of raffia palm fibre and groundnut shell particulate/epoxy (RPF/GSP/E) hybrid composites have been studied. Raffia palm fibres were treated with 10% NaOH solution at room temperature, and groundnut shell particulate of different sizes; 75 µ, 150 µ and 300 µ were also chemically treated with 10% NaOH solution at room temperature. The hybrid composite was produced by hand lay-up technique with (10%, 20%, 30%, 40%, and 50%) reinforcements of raffia palm fibre and ground nut shell particulate in the ratio of 1:1. The treated fibres were taken with required weight fractions laid into the mould of size 200 × 150 × 5 mm^3. Groundnut shell particulates were also taken with the required weight fraction, mixed with epoxy resin and the mixture was stirred thoroughly before pouring into the mould. Care was taken to avoid formation of air bubbles during pouring and the produced composite was cured under a load of 25 kg for 24 hours before it was removed from the mould. Effects of loading on the tensile, flexural and impact properties of the composite were evaluated. The significant findings of the results were that: tensile strength varied from 1.88 MPa to 9.56 MPa; Modulus of rupture (MOR) varied from 1.92 MPa to 41.6 MPa. While the modulus of elasticity, (MOE) values were in the range of 131.1 MPa to 4720 MPa and impact strength varied from 0.3 kJ/m^2 to 1.6 kJ/m^2. From the results obtained, the optimum mechanical properties were obtained at 40% loading of RPF/300 µ GSP/E composite. Considering these results, the composite material can be considered as an alternative material for use in automotive interior panels such as boot liner, side and door panels, rear storage shelf and roof cover.

Keywords

Hand lay-Up, Hybrid Composite, Modulus of Rupture, Modulus of Elasticity, Raffia Palm Fibres/Groundnut Shell Particulate

1. Introduction

Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form. The primary advantage of composite materials is their inherent ability to be custom tailored to a specific design situation. Constituents like fibres and matrix material can be used in different combinations, amounts, and architectures to obtain an optimal material composition.

The deployment of polymer composites with natural fibre and fillers as a sustainable alternative material for some engineering applications, particularly in aerospace and automobile applications is being pursued. Some of the common natural fibres are raffia palm, sisal, jute, hemp, coir, groundnut, bamboo and other fibrous materials. The advantages of natural fibres are low cost, light weight, easy production and being friendly to the environment [1].

On the other hand, there are some drawbacks to the use of natural fibres such as their low mechanical properties and high moisture absorption. The latter is due to their hydrophilic nature that is detrimental to many properties, including dimensional stability [2] [3].

Some composite components (e.g. for the automotive industry), previously manufactured with glass fibres are now being produced with natural fibres. Applications including door panels, truck liners, instrument panels, interior roofs, parcel shelves, among other interior components, are already in use in European cars due to the more favourable economic, environmental and social aspects of the vegetable fibres [1]. In recent years, natural fibre along with mineral fillers has been used to fabricate hybrid composite with improved mechanical properties. Hybrid composites are materials made by combining two or more different types of fibres in a common matrix. The hybrid composite material finds a lot of applications such as in the automobile sector as replacement for glass fibres which already exists.

Hybridization of two types of fibres can offer some advantages over using each of the fibres alone in a single polymer matrix. Hybrid composite materials offer a combination of strength and modulus that are either comparable to or better than many pure materials [4].

Many researchers have developed hybrid composites containing both natural and synthetic fillers. The hybrid composites showed better mechanical properties than mono filler materials [5] [6]. In a study by [7], properties of raffia palm interspersed fibre (RPIF) filled high density polyethylene (HDPE) have been investigated at different levels of filler loadings, 0 to 60 wt%. Maleic anhydride-graft polyethylene (MA-g-PE) was used as a compatibilizer. Raffia palm interspersed fibre was prepared by grinding and sieving to a particle size of 150 µ. Results showed that the tensile strength and elongation at break of the blends decreased with increase in raffia palm interspersed fibre (RPI) loadings but addition of MA-g-PE was found to improve these properties. The mechanical properties of short random oil palm fibre reinforced epoxy (OPF/epoxy) composites were studied by [8], in the study, composite plates with different volume fractions (5, 10, 15 and 20 vol.%) of oil palm fibre were fabricated by hand-layup technique. The tensile and flexural properties showed inverse variation with fibre loading. The maximum tensile strength values were obtained for the sample with 5 vol.% fraction of fibres and beyond that, there was no significant change. Also, in a study conducted by [9], the flexural strength—the resistance to fracture—of raffia palm fibre-cement composites for low cost roofing tiles was investigated. The results showed that addition of raffia palm fibre to cement composites increases the flexural strength by more than 100% in comparison with the control, with zero per cent fibre volume fractions. It was recommended that raffia palm fibre be used for the manufacture of wall, ceiling and roofing tiles.

The mechanical properties of groundnut shell reinforced urea formaldehyde composites were investigated by [10]. Tensile and compressive tests were carried out giving yield strength values of the samples in the range 29.92 - 49.08 MPa and compressive strength 59.48 - 94.370 MPa. It was observed that the prepared samples exhibit lower tensile strength than the compressive strength due to brittleness of the composites. It was also found that increased volume of groundnut shell up to 12% increases the strength and beyond this value, the strength decreases. An established shell volume of 12% in the sample gives the optimum composite material for application as a particle board. [11] prepared the composite with different weight% of randomly distributed groundnut shell in polymer matrix to elucidate the optimization of thermal properties such as thermal conductivity, linear thermal expansion and specific heat of groundnut shell particles reinforced polymer composite materials. The composite specimens were prepared with different weight percentages of randomly distributed groundnut shell particles in polymer matrix. Thermo Gravimetric Analysis (TGA) was also carried out to ascertain the thermal stability of these composites. The study found that using groundnut shell particles as reinforcement for polymer matrix reduced thermal conductivity and could successfully develop beneficial composites and can be used for thermal applications. [12] investigated the suitability of groundnut shell as a constituent material in concrete by replacing proportions by volume of fine aggregate (river sand) with groundnut shells. Physical properties of cement, groundnut shells and aggregates were determined. Concrete cubes measuring $150 \times 150 \times 150\ mm^3$ were cast. Groundnut shells were used to replace fine aggregate at 0, 5%, 15%, 25%, 50% and 75% replacement levels. Compressive strengths and density values of the concrete cubes were evaluated at 28 days at different percentage replacement levels. The significant findings of the work were that, increase in percentage of groundnut shells in the cubes led to a corresponding reduction in densities of the cubes and compressive strength values. At a replacement value of 25% and above, of fine aggregate with groundnut shells, lightweight concrete was produced which could be used where low stress is required. Hence groundnut shells can be used for the production of lightweight concrete. [13] fabricated composites consisting of reinforcement in the hybrid combination such as sisal-coconut spathe, sisal-ridge gourd and coconut spathe-ridge gourd with fibres varying from 5% to 30 wt%. The tensile strength reached a maximum value of 22 MPa at 25% weight fraction of fibres. This result explained that the incorporation of different natural fibres (instead of a synthetic and a natural fibre) as reinforcements is also a very practical approach.

In this work, epoxy based hybrid composites were produced with raffia palm fibre and ground nut shell particulate as the reinforcing materials. To reduce the effect of moisture absorption of natural fibres and improve mechanical properties, the fibres were treated with 10% NaOH solution to improve the surface properties and provide better adhesion with the matrix. Alkaline treatment of cellulosic fibres with sodium hydroxide is a well-known method which has been employed to improve fibre-polymer matrix interfacial bonding [14]. This treatment reduces the hydrophilicity of the fibres and increases its hydrophobicity by the removal of natural fats and waxes from cellulosic fibre surfaces. The tensile, impact and flexural properties of the produced composite were studied.

2. Materials and Equipment

Epoxy resin: Araldite LY-556 and Hardener: (2 aminoethylethane1, 2 diamine) HY 951 were obtained from Lagos, Nigeria. Raffia palm fibres and Groundnut shells were obtained locally from Ikov, Ushongo local government area of Benue State, Nigeria. Sodium hydroxide (NaOH), Distilled water, Wax, Hand gloves and Acetone were obtained from Makurdi, Benue State, Nigeria. The equipment used include: Set of standard laboratory Sieves, Monsanto Tensometer Type "W", Universal Materials Testing Machine and Charpy Impact Testing Machine.

2.1. Methods

1) The groundnut shells were collected from a groundnut processing centre in Ushongo local government area of Benue state, Nigeria. Cleaned and dried groundnut shells were initially washed with distilled water to remove the sand and other impurities. The washed shells were sun dried and ground. The shell particles were treated using alkali treatment method by soaking the clean groundnut shell particles in 10% NaOH solution for 2 hours at room temperature and then were washed with distilled water. The washed shells were again dried under the sun. The particles were sieved through 75 μ, 150 μ and 300 μ standard test sieves to get different sizes of groundnut shell particles.

2) The raffia palm fibres were collected from raffia palm trees around a stream at Ikov, in Ushongo local government of Benue State, Nigeria. The pinnate leaves of the raffia palm were pulled out from the leaf stalks. Thereafter, the raffia fibres were taken off from the pinnate leaves. The fibres were washed thoroughly and allowed to dry under the sun. The raffia palm fibres were treated

using alkali treatment method by soaking the clean raffia palm fibres in 10% NaOH solution for 1 hour at room temperature. The fibres were then washed thoroughly in plentiful of distilled water to remove the excess NaOH (or non-reacted alkali). The fibres were again sun dried and cut into fibre lengths of 10 mm to avoid fibre entanglement during production of the composite.

2.2. Preparation of Hybrid Composite

The fabrication of the composites was carried out by simple hand lay-up technique. A mould of $200 \times 150 \times 5$ mm^3 made of wood was used for casting the composite laminate. A mould release agent (wax), was first applied on all the surfaces of the mould, and allowed to dry. A thin film was formed on the mould when the wax dried. The thin film formed acts as the mould release agent. Raffia palm fibres of length 10 mm were laid in the mould by hand.

The epoxy resin and hardener were mixed in the ratio of 4:1 by weight. These were thoroughly mixed in a plastic container. Measured quantities of groundnut shell particulate were added in the plastic container and the mixture was again stirred for 15 minutes and thoroughly mixed before it was poured into the mould. The fibres in the mould were saturated with resin that was already mixed with groundnut shell particulate, and then were rolled using a roller to ensure good contact and freedom from porosity, and the produced composite was finally cured. The closed mould was kept under a load of 25 kg at room temperature for about 24 hours before the composite was removed from it. The composite was then post cured in air for 27 days at room temperature.

The composites were fabricated with 10, 20, 30, 40, and 50% reinforcements of raffia fibre and groundnut shell particulate in the ratio of 1:1. Samples were designated as A, B, C, D, and E respectively. Specimens of suitable dimensions were cut for mechanical testing. The produced composite is shown in **Figure 1**. Utmost care was taken to maintain uniformity in the samples. **Table 1** shows the percentage composition of raffia palm fibre/groundnut shell particulate/epoxy (RPF/GSP/E) hybrid composite.

Figure 1. Fabricated composite laminate (5 mm thickness).

Table 1. The percentage composition of raffia palm fibre/groundnut shell particulate/epoxy (RPF/GSP/E) hybrid composite.

Reagents	Size	W% (Grams)				
Sample		A	B	C	D	E
Raffia fibres	10 mm	5	10	15	20	25
Groundnut shell particulate	75 µ	5	10	15	20	25
Epoxy		90	80	70	60	50
Raffia fibres	10 mm	5	10	15	20	25
Groundnut shell particulate	150 µ	5	10	15	20	25
Epoxy		90	80	70	60	50
Raffia fibres	10 mm	5	10	15	20	25
Groundnut shell particulate	300 µ	5	10	15	20	25
Epoxy		90	80	70	60	50

2.3. Mechanical Testing

2.3.1. Tensile Test

The tensile strength of the composites was measured with Monsanto Tensometer Type "W" in accordance with the ASTM D638 procedure. The test was conducted by gripping each end of a reduced section specimen and slowly pulling it until catastrophic failure occurs. Three samples were tested and the average values of tensile strength and elongation at fracture were calculated.

2.3.2. Flexural Test

The flexural test was performed using a 100 kN capacity universal materials testing machine. This was done in accordance with ASTM D790 using the 3-point bending fixture, utilizing centre loading on a simple supported beam. The dimension of the sample was 100 mm × 30 mm × 5 mm. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports. Three samples were tested and the average values of the modulus of rupture and modulus of elasticity were calculated. The modulus of rupture (MOR) and the modulus of elasticity (MOE) of the composite specimen were determined using the following equation:

$$\text{Modulus of Rupture}\ (\text{MOR}) = \frac{3pl}{2bt^2}(\text{MPa}) \quad (1)$$

$$\text{Modulus of Elasticity}\ (\text{MOE}) = \frac{pl^3}{4bt^3}(\text{MPa}) \quad (2)$$

where, p is max. Load applied on test specimen (N):

l is gauge length (mm);

b is the width of specimen (mm);

t is thickness of specimen (mm).

2.3.3. Impact Test

The impact strength of the samples was determined using a 25 J capacity Charpy

Impact Testing Machine according to ASTM standard D256. In this method, the specimen of size 80 mm by 10 mm by 10 mm is supported horizontally as a simple beam and fractured by a blow delivered in the middle of the specimen by the pendulum. Three samples were tested and the average of the values of the energy absorbed was recorded. The equation below was used to evaluate the impact strength:

$$I = \frac{K}{A} \tag{3}$$

where I is the impact strength of specimen in kJ/m^2;

K is the energy required for fracture in kilo Joules;

A is the area of cross section in m^2.

3. Results and Discussion

3.1. Tensile Test

3.1.1. Tensile Strength

The computed tensile strength values of raffia palm fibre and groundnut shell particulate epoxy hybrid composite (RPF/GSP/E) specimens are shown in **Figure 2**. The experimental results showed that the reinforcements had created some reinforcing effect. In all the samples, there was increase in tensile strength as filler loading increased up to 40%. It is observed that, RPF/75 μm GSP/E, increase in tensile strength with loading was continuous up to 50% reinforcement. However, (RPF/150 μ GSP/E and RPF/300 μ GSP/E) with further increment in the reinforcement up to 50%, a decrease in the tensile strength was observed. The decrease could be due to weak filler-matrix adhesion. This is as a result of insufficient wetting of fillers by the resin for higher reinforcement which resulted to increase in voids in the samples. During tensile loading partially separated micro spaces are created that obstructs stress propagation between the fibre and the matrix [15]. As the fibre loading increases, the degree of obstruction increases, which in turn decreases the strength of the specimens.

Generally, from the results of the experiment depicted in **Figure 2**, there is a steady increase in tensile strength with increased reinforcement indicating a maximum tensile strength of 9.56 MPa for RPF/300 μ GSP/E at 40% reinforcement. At 40% filler content for RPF/300 μ GSP/E the tensile strength was at maximum because the stress transferred by the matrix was supported by the fillers. The mechanical properties of particulate-filled polymer micro and nano-composites are affected by particle size, particle content and particle/matrix interfacial adhesion [16]. Composite strength and toughness are strongly affected by all three factors, especially particle/matrix adhesion.

3.1.2. The Young Modulus

Figure 3 shows the trend of Young modulus of raffia palm fibre/groundnut shell particulate reinforced epoxy hybrid composites. The Young modulus was found to increase as the reinforcement increased in RPF/75 μ GSP/E and RPF/300 μ GSP/E samples, while RPF/150 μ GSP/E did not follow a specific pattern this

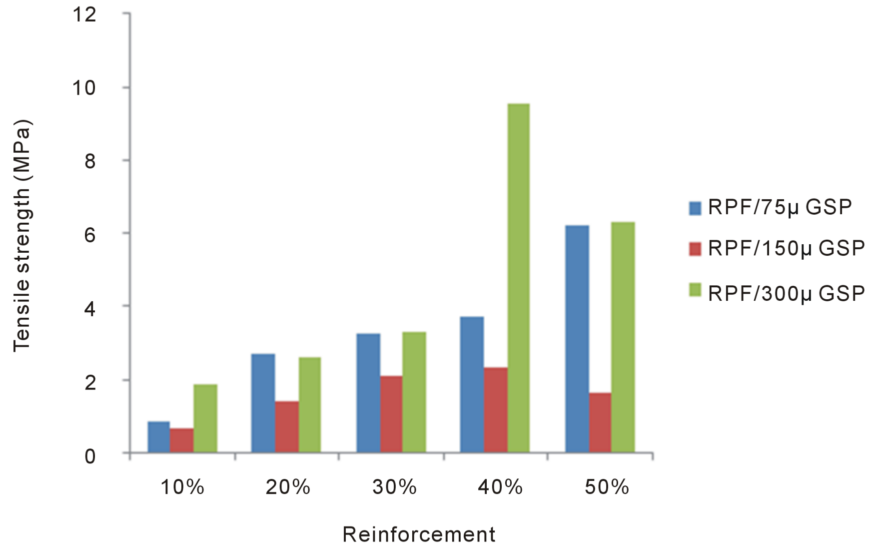

Figure 2. Effect of reinforcement on tensile strength of RPF/GSP epoxy composite.

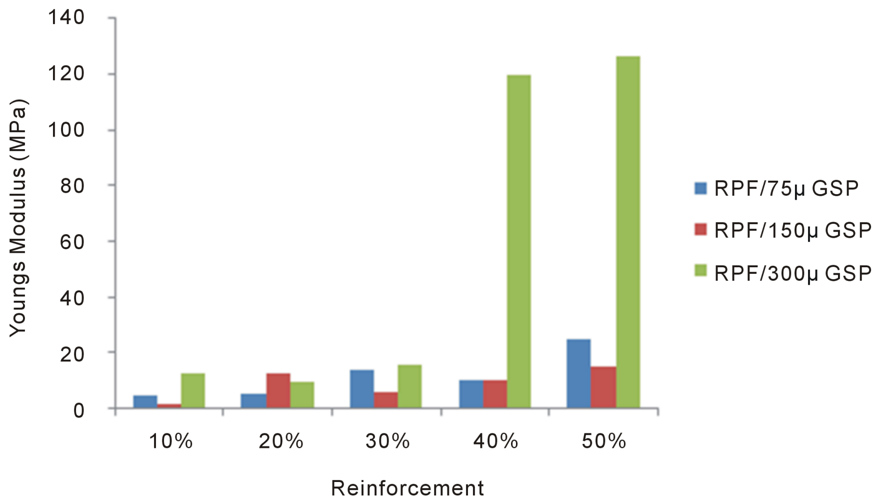

Figure 3. Effect of reinforcement on young modulus of RPF/GSP epoxy composite.

could be due to the agglomeration of fillers in the samples. Similar results have been reported by other researchers, that the Young's modulus increases with an increase in reinforcement [17]. This behaviour may possibly be explained that Young modulus depends on the filler content rather than particle-matrix interface [11]. Furthermore, increase in Young modulus for higher filler content is due to the higher stiffness of the reinforcing particles rather than the matrix material. Owing to this, overall stiffness of the composite specimens increased and thus Young modulus was enhanced. From the results of the experiment depicted in Figure 3, it has been observed that sample E of RPF/300 μ GSP/E (50 wt%) gave the maximum Young modulus value of 126.4 MPa. This behaviour can be traced to the compatibility of the RPF/300 μ GSP with the epoxy matrix and the interfacial bond between fillers and matrix. According to [18], modulus in the glassy state is determined primarily by the strength of the intermolecular forces and the way the polymer chains are packed.

3.1.3. Per Cent Elongation at Fracture

The result of the per cent elongation at fracture is shown in Figure 4. The results showed that, the per cent elongation at fracture of RPF/75 μ GSP/E composite increased to a maximum at 20% loading and decreased with further increase in reinforcement.

The per cent elongation at fracture of RPF/150 μ GSP/E composite decreased as the reinforcement increased to 20%. The per cent elongation increased to a maximum at 30% loading but decreased on further loading up to 50%.

The elongation at fracture of RPF/300 μ GSP/E composite increased to a maximum at 20% reinforcement but decreased with further loading up to 50%.

Generally, from the results of the per cent elongation at fracture of RPF/GSP/E composite, the per cent elongation at fracture decreased with higher loading. It is observed that RPF/300 μ GSP/E composite gave the lowest per cent elongation at fracture except for 20% loading with an elongation of 28%.

RPF/75 μ GSP/E composite gave the highest per cent elongation at fracture except for 10 and 30% loading with elongations of 20% and 24% respectively.

While, RPF/150 μ GSP/E composite gave the highest per cent elongation at fracture at 10% and 30% loadings with elongations of 36% and 38% respectively.

3.2. Flexural Strength

The computed values of modulus of rupture (MOR) and modulus of elasticity (MOE) of the composite specimens are shown in Figure 5 and Figure 6 respectively, MOR of RPF/75 μ GSP/E samples is in the range of 1.92-22.4 MPa, indicating the highest value of 22.4 MPa for sample D (40% reinforcement). By further increasing the filler content up to 50%, MOR value decreased due to weak

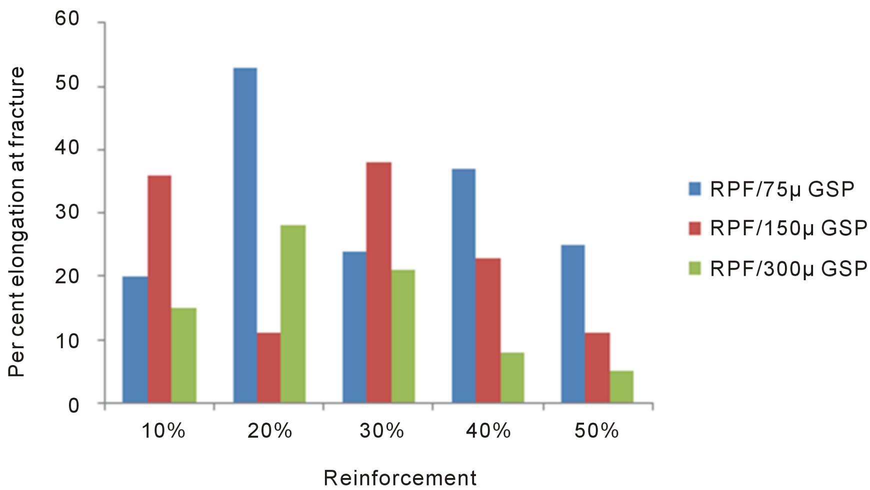

Figure 4. Effect of reinforcement on per cent elongation at fracture of RPF/GSP/E composite.

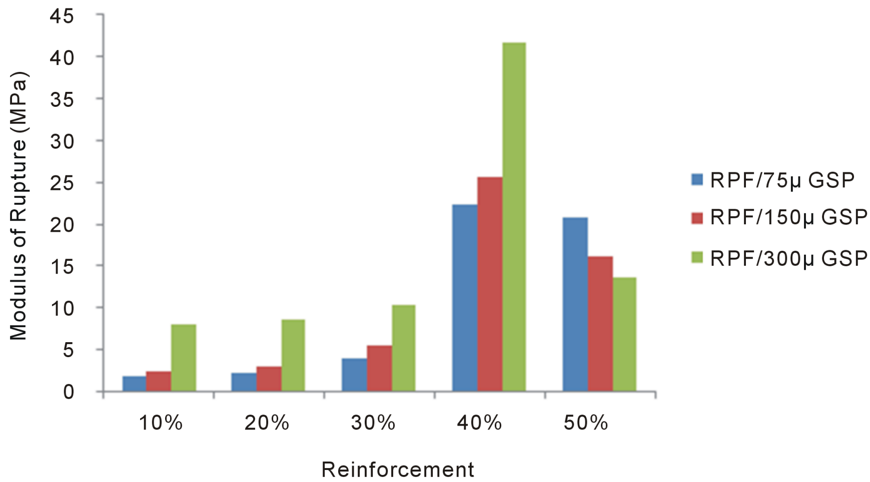

Figure 5. Effect of reinforcement on modulus of rupture (MOR) of RPF/GSP epoxy composite.

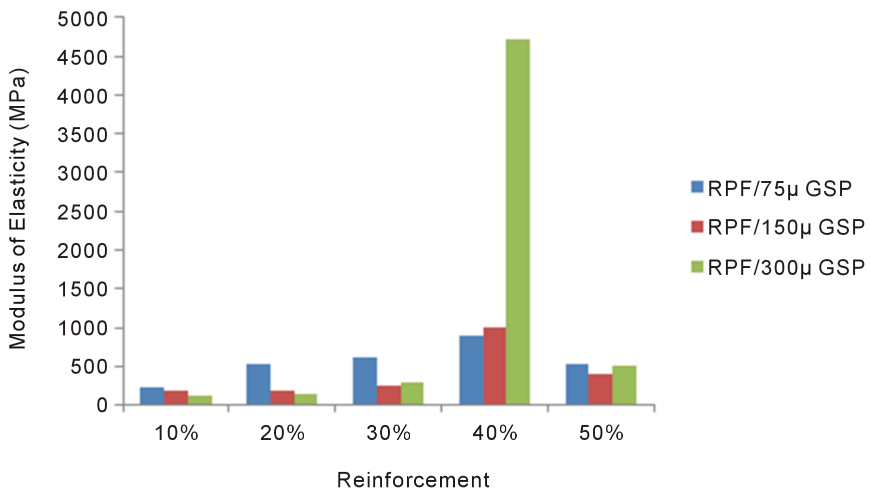

Figure 6. Effect of reinforcement on modulus of elasticity (MOE) of RPF/GSP epoxy composite.

filler-matrix adhesion as a result of insufficient wetting of fillers by the resin for higher filler content. Similar results were obtained for RPF/150 μ GSP/E samples where MOR of samples ranged from 2.40 - 25.6 MPa. Also, for RPF/300 μ GSP/E, MOR ranged from 8.0 - 41.6 MPa. Generally, it is observed in Figure 5 that, MOR increased as the loading increased and peaked at 40% loading in all samples. Similar results have been reported by other researchers that the flexural strength decreases after 40 wt% of filler loading [19] [20].

Similar Behaviour was exhibited by the composite samples for Modulus of Elasticity (MOE) property. MOE of samples increased with increase in filler loading which could be attributed to enhancement in stiffness of the composite with the addition of reinforcement filler, which is because reinforcing particles have higher stiffness than the weak matrix. Similar results were also reported by several authors [21] [22].

MOE of the samples is in the range of 223.8 - 891.5 MPa with the sample D (40% reinforcement) of RPF/75 μ GSP/E gave a maximum MOE of 891.5 MPa. Similar trend is observed for RPF/150 μ GSP/E with MOE in the range of 172.5 - 1011.4 MPa. Same trend was observed for RPF/300 μ GSP/E, MOE of these samples, ranged from 131.1 - 4720 MPa with Sample D (40% reinforcement) having the highest MOE of 4720 MPa among all the samples.

3.3. Impact Strength

The experimental results of impact strength of raffia palm fibre and groundnut shell particulate reinforced epoxy hybrid composite are displayed in **Figure 7**. The results, shows a steady increase in impact strength with increase in filler content, indicating 1.5 kJ/m^2 at 50% of filler addition of RPF/75 μ GSP/E. Similar results was also observed for RPF/150 μ GSP/E with sample D (40% reinforcement) having the highest impact strength of 1.6 kJ/m^2, with a decrease in impact strength for further increase in filler content up to (50% reinforcement). This may be attributed to the weak interfacial interaction between the filler and matrix as well voids and agglomeration of fillers for higher filler content. For RPF/300 μ GSP/E, impact strength increased continually as the reinforcement rises up to 50% reinforcement, giving an impact strength of 1.6 kJ/m^2. Similar behaviour of the composite specimens was also observed by [17] that impact strength decreases for higher filler loading beyond 50% reinforcement.

4. Conclusions

A hybrid composite using raffia palm fibre and groundnut shell particulate as fillers and epoxy resin as matrix has been developed. It was observed that, the addition of natural fibres to epoxy improved mechanical properties up to some weight% and further decreased with increased filler content. It was shown that, filler loading had more impact on the mechanical properties of the composite.

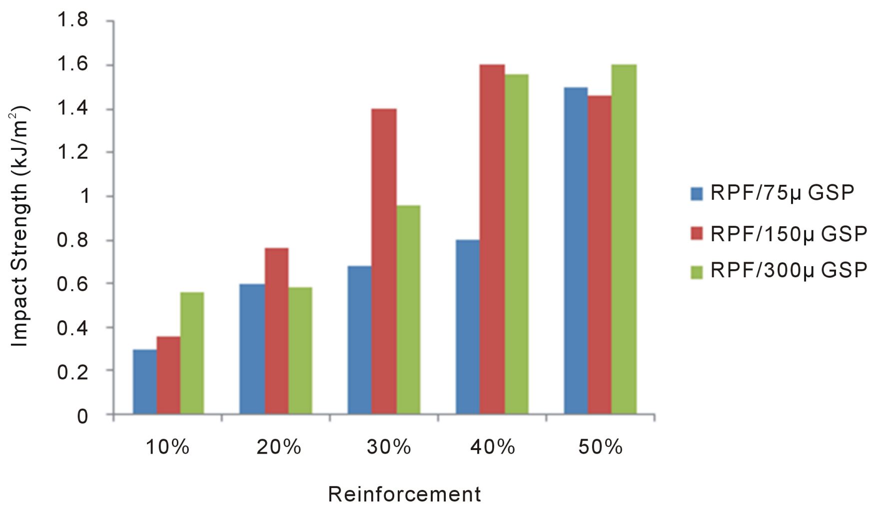

Figure 7. Effect of reinforcement on impact strength of RPF/GSP epoxy composite.

4.1. Tensile Properties of RPF/GSP/E Composite

Sample D (40 weight% of RPF/300 μ GSP/E) gave the maximum tensile strength of 9.56 MPa. The sample E of RPF/300 μ GSP (50 wt%) gave the maximum Young modulus of 126.4 MPa. The results of the per cent elongation at fracture of RPF/GSP/E composite, showed that, elongation at fracture of the composite decreased at higher loadings. RPF/300 μ GSP/E composite gave the lowest per cent elongation at fracture except for 20% loading with an elongation of 28%.

RPF/75 μ GSP/E composite gave the highest per cent elongation at fracture except for the 10% and 30% loading with elongations of 20% and 24% respectively.

While, RPF/150 μ GSP/E composite gave the highest per cent elongation at fracture at 10% and 30% loadings with elongations of 36% and 38% respectively.

4.2. Flexural Properties of RPF/GSP/E Composite

Sample D (40 weight% of RPF/300 μ GSP/E) gave the highest value of modulus of rupture (MOR) of 41.6 MPa. The analysis of Modulus of elasticity (MOE) also shows that, Sample D (40% wt of RPF/300 μ GSP/E) gave the highest MOE of 4720 MPa.

4.3. Impact Properties of RPF/GSP/E Composite

The results of the impact strength showed that, sample D (40% wt of RPF/150 μ GSP/E) gave the highest impact strength of 1.6 kJ/m^2. Sample E (50% wt of RPF/300 μ GSP/E) also gave impact strength of 1.6 kJ/m^2.

From the results obtained, groundnut shell particle size of 300 μ gave better mechanical properties when hybridized with raffia palm fibres. Considering the mechanical properties obtained, RPF/300 μ GSP reinforced epoxy composite samples gave optimum mechanical properties.

According to [11], based on the European Norms (EN) standards, particleboard panels for general use and furniture manufacture should have a minimum MOE of 1600 MPa and a minimum MOR of 11.5 and 13 MPa for general purpose and interior fittings (including furniture), respectively. Sample D (40% RPF/300 μ GSP/E) produced in this research gave higher MOE and MOR values than those specified for general purpose and interior fittings requirements for particle boards. These can be considered for use in the interior of automobiles as internal panels, as boot liner, side and door panels, rear storage shelf and roof cover of commercial buses due to the material's moderate mechanical properties.

References

[1] Joshi, S.V., Drzal, L.T., Mohanty, A.K. and Arora S. (2004) Are Natural Fibre Composites Environmentally Superior to Glass Fibre-Reinforced Composites? *Composites Part A*: *Applied Science and Manufacturing*, **35**, 371-376. https://doi.org/10.1016/j.compositesa.2003.09.016

[2] Arpitha G.R., Sanjay, M.R., Laxmana Naik, L. and Yogesha, B. (2014) Mechanical

Properties of Epoxy Based Hybrid Composites Reinforced with Sisal/SIC/Glass Fibers. *International Journal of Engineering Research and General Science*, **2**, 398-405.

[3] Samuel, O.D., Agbo, S. and Adekanye, T.A. (2012) Assessing Mechanical Properties of Natural Fibre Reinforced Composites for Engineering Applications. *Journal of Minerals and Materials Characterization and Engineering*, **11**, 780-784. https://doi.org/10.4236/jmmce.2012.118066

[4] Rowell, R.M. (1997) Utilization of Natural Fibres in Plastic Composites, Problems and Opportunities. *Journal of Thermoplastic Composites Materials,* **15**, 281-300.

[5] Varada, A., Rajulu, G., Babu R. and Ganga, D. (2005) Mechanical Properties of Short Natural Fiber *Hildegardia populifolia*-Reinforced Styrenated Polyester Composites. *Journal of Reinforced Plastics Composite*, **24**, 423-428. https://doi.org/10.1177/0731684405044896

[6] John, K. and Venkata Naidu, S. (2004) Sisal Fiber/Glass Fiber Hybrid Composites: The Impact and Compressive Properties. *Journal of Reinforced Plastics Composites*, **23**, 1253-1258. https://doi.org/10.1177/0731684404035270

[7] Henry, C.O. (2013) Properties of Raphia Palm Interspersed Fibre Filled High Density Polyethylene. *Advances in Materials Science and Engineering*, **2**, 45-54.

[8] Yusoff, M.Z.M., Salit, M.S., Ismail, N. and Wirawan, R. (2010) Mechanical Properties of Short Random Oil Palm Fiber Reinforced Epoxy Composites. *Sains Malaysiana*, **39**, 87-92.

[9] Odera, R.S (2014) Optimization of the Flexural Strength of Raffia Palm Fibre-Cement Composite. *Journal of Engineering Trends in Engineering and Applied Sciences*, **2**, 294-297.

[10] Aji, I.S., Zainudin, E.S., Abdan, K., Sapuan, S.M. and Khairul, M.D. (2002) The Mechanical Properties of Groundnut Shell Reinforced Urea Formaldehyde Composite. *Journal of Composite Materials*, **47**, 979-990. https://doi.org/10.1177/0021998312444147

[11] Raju, G.U. and Kumarappa, S. (2012) Experimental Study on Mechanical Properties of Groundnut Shell Particle Reinforced Epoxy Composites. *Journal of Reinforced Plastics and Composites*, **30**, 1029-1037. https://doi.org/10.1177/0731684411410761

[12] Sada, B.H and Amartey, Y.D. (2013) An Investigation into the Use of Groundnut Shell as Fine Aggregate Replacement. *Nigerian Journal of Technology*, **32**, 54-60.

[13] Girisha, C.S. (2012) Tensile Properties of Natural Fiber-Reinforced Epoxy-Hybrid Composites. *International Journal of Modern Engineering Research*, **2**, 471-474.

[14] Mohanty, A., Khan, M. and Hinrichsen, G. (2000) Surface Modification of Jute and Its Influence on Performance of Biodegradable Jute-Fabric/Biopol Composites. *Composite Science and Technology,* **60**, 1115-1124. https://doi.org/10.1016/S0266-3538(00)00012-9

[15] Ismail, H., Edyhan, M. and Wirjosentono, B. (2002) Bamboo Fiber Filled Natural Rubber Composites: The Effects of Filler Loading and Bonding Agent. *Polymer Testing*, **21**, 139-144. https://doi.org/10.1016/S0142-9418(01)00060-5

[16] Fu, S., Feng, X., Lauke, B. and Mai, Y. (2008) Effects of Particle Size, Particle/Matrix Interface Adhesion and Particle Loading on Mechanical Properties of Particulate-Polymer Composites. *Composites Part B: Engineering*, **39**, 933-961.

[17] Haque, M.M., Hasan, M., Islam, M.S. and Ali, M.E. (2009) Physico-Mechanical Properties of Chemically Treated Palm and Coir Fiber Reinforced Polypropylene Composites. *Journal of Reinforced Plastics and Composites*, **29**, 1734-1742.

[18] Pothan, L., Ommen, Z. and Thomas, S. (2003) Dynamic Mechanical Analysis of Banana Fiber Reinforced Polyester Composites. *Composites Science and Technology*, **63**, 283-293. https://doi.org/10.1016/S0266-3538(02)00254-3

[19] Zampaloni, M., Pourboghrat, F., Yankovich, S., Rodgers, B., Moore, J. and Drzal, L. (2007) Kenaf Natural Fiber Reinforced Polypropylene Composites: A Discussion on Manufacturing Problems and Solutions. *Composites Part A*, **38**, 1569-1580. https://doi.org/10.1016/j.compositesa.2007.01.001

[20] Ozturk, S. (2010) Effect of Fiber Loading on the Mechanical Properties of Kenaf and Fiberfrax Fiber-Reinforced Phenol-Formaldehyde Composites. *Journal of Composite Materials*, **44**, 2265-2288. https://doi.org/10.1177/0021998310364265

[21] Lou, C.W., Lin, C.W., Lei, C.H., Su, K.H., Hsu, C.H., Liu, Z.H., *et al.* (2007) PET/PP Blend with Bamboo Charcoal to Produce Functional Composites. *Journal of Materials Processing Technology*, **192**-**193**, 428-433.

[22] Akgul, M. and Tozluoglu, A. (2008) Utilizing Peanut Husk (*Arachis hypogaea* L.) in the Manufacture of Medium-Density Fiberboards. *Bioresource Technology*, **99**, 5590-5594. https://doi.org/10.1016/j.biortech.2007.10.041