American Journal of Materials Science and Engineering, 2014, Vol. 2, No. 4, 45-53
Available online at http://pubs.sciepub.com/ajmse/2/4/1

DOI:10.12691/ajmse-2-4-1

Property Evaluation of Hybrid OPEBF/Banana/Glass Fiber Reinforced Unsaturated Polyester Composites

Ishaya M. Dagwa[1,*], Josiah O. Ohaeri[2]

[1]Department of Mechanical Engineering, Main Campus, University of Abuja, Abuja, FCT, Nigeria
[2]Department of Mechanical Engineering, Ahmadu Bello University, Samaru- Zaria, Kaduna State, Nigeria
*Corresponding author: dagwaim@gmail.com

Received August 13, 2014; Revised September 05, 2014; Accepted September 23, 2014

Abstract The physical (density and water absorption) and mechanical (tensile, flexural, impact and hardness) properties of banana empty fruit bunch fiber -glass fiber- oil palm empty fruit bunch particles- reinforced polyester composite were investigated. The natural fibers were extracted and processed locally. Thereafter, the test specimens were prepared using polyester resin with different compositions and prepared in accordance with ASTM standards. The results showed that as the banana fiber content was increased, there was a corresponding decline in the flexural strength. However, increasing the glass fiber content resulted in a corresponding increase in flexural strength. Composite with OPEBF 5 wt % banana fiber 10wt% /glass fiber10 (wt%) produced high impact strength of 55.556J/m^2 representing 1568.67% improvement over that of the virgin unsaturated polyester. It was discovered that banana fiber of 15wt% and glass fiber of 5wt% hybrid composite had the highest hardness (3.55HV) representing 136.67% improvement on the hardness of the polyester (1.5HV). It was observed that the hardness of the samples was influenced by increase in banana fiber content in the composite. Thus, banana fiber composite could be considered for applications in areas where high impact strength is a requirement such as in some parts of automobile vehicle.

Keywords: *composite, banana fiber, glass fiber, polyester resin, oil palm empty bunch fruit fiber, mechanical properties*

Cite This Article: Ishaya M. Dagwa, and Josiah O. Ohaeri, "Property Evaluation of Hybrid OPEBF/Banana/Glass Fiber Reinforced Unsaturated Polyester Composites." *American Journal of Materials Science and Engineering*, vol. 2, no. 4 (2014): 45-53. doi: 10.12691/ajmse-2-4-1.

1. Introduction

A new era of research using natural fibers in diversified fields arrived with the emergence of polymers in the 19th century. Over the past decades, natural fibers have attracted the interest of material scientists, engineers, researchers and even the industrial players due to their advantages when compared to conventional or synthetic fibers. Environmental concerns account for this re-direction of interest into natural fibers for use in composite manufacture. The advantages of using natural fibers include, low cost, low density, specific properties comparable to those of synthetic fibers, ease of separation, carbon dioxide seizure, non-corrosiveness, reduced tool wear, reduced dermal and respiratory irritation [1,2]. Other properties include; biodegradable, abundantly available, renewable, low abrasive nature, interesting specific properties and exhibition of good mechanical properties [3-8]. Additionally, they have relatively high strength and high stiffness [9]. Generally, fibers possess higher modulus than the matrix materials, such that the load is transferred to the fiber from matrix when composites are subjected to external loads [10].

Natural fibers have been applied extensively in buildings and many engineering fields and these range from household to more sensitive and specialized areas such as space and aircrafts [10,11,12,13]. Natural fibers are hydrophilic in nature; they form composites with weak interface if not modified. Studies reveal that though the natural fibers have some superior properties when compared to their synthetic fiber counterparts, they also have serious problems such as polarity which creates incompatibility problems with many polymers, poor resistance to moisture, limited processing temperature and low dimensional stability [14,15].

The natural fibers carry the hydroxyl group as its main back structure, obtained from cellulose and lignin; they can be easily modified to suit specific applications. Hence, chemical treatments have to be undertaken to improve the adhesion or interfacial bonding between natural fibers and polymers. Chemically, the hydroxyl groups are involved in the hydrogen bonding within the cellulose molecules and these therefore reduces its activity and affinity towards the matrix. Chemical modifications activate these groups and introduce new moieties which effectively interlock with the matrix [16,17].

Research findings reveal that banana fibers have high cellulose content with high mechanical properties in terms of its tensile strength and modulus [17]. Equally, Laly, et.al revealed that the tensile strength of banana – glass hybrid composites displayed a linear increase as the volume fraction of glass was increased [18,19]. Similarly, analysis of the mechanical properties of short banana fiber reinforced natural rubber composites by Ragavendra et al. al. [18,19] showed that increase in fiber concentration improved the tensile strength while Sumaila et al [19] studied the effects of fiber surface modifications on the strength of composites formed. They investigated the effects of banana fiber/epoxy composites and concluded that the fiber length affects the composite's mechanical and physical properties with critical fiber length recorded at 15mm in the same manner, Corbiere-Nicollier et. al. [20] reported a good flexural strength on Kraft pulped banana fiber composite in terms of its physical and mechanical properties when used in a banana-fiber-cement composite.

Oil palm empty fruit bunch fibers have great potentials as reinforcing materials in polymer [18,19,20]. The properties of the fibers such as tensile strength, flexural strength, and rigidity depend on the alignment of cellulose fibrils, which are generally arranged along the fiber length [19]. Oil palm empty fruit bunch (OPEFB) is one of the major biomass type generated massively in oil palm producing communities of Nigeria. Amongst the various oil palm fiber sources available, EFB has the potential to yield up to 73% fibers and becomes the preferred material for the bio-composite industry based on its high availability and low cost [20]. Particularly the cellulose content [21] and high toughness [22] of OPEFB make it suitable for composite applications.

Glass fiber is a chemical inorganic fiber obtained from molten glass of a specific composition [23]. Glass fibers find applications in high performance aircraft, boats, automobiles, bath tubs and enclosures, hot tubs, septic tanks, water tanks, roofing, pipes, cladding and external door skins [24]. Polyester resins are unsaturated resins formed by the reaction of dibasic organic acids and polyhydric alcohols. They are condensation polymers. Polyester resins are thermosetting and therefore cure exothermally. It is cheaper compared to other resins; hence its expansive use [23,24]. Unsaturated polyester resins have a good balance of mechanical, electrical and chemical properties [24]. Globally, it is estimated that millions of tons of banana and banana plantation production exist and even more exist for oil palm worldwide giving rise to abundance in banana empty fruit bunch and oil palm empty fruit bunch as waste materials – for utilization in composite manufacture.

In view of the aforementioned attributes of OPEFB, in this work, a constant weight of OPEFB fibers, which was ground into a fine powder, was purposefully introduced to the composites under investigation. Hence, this research aims to undertake a study on the physical and mechanical properties of hybridized OPEBF/Banana/Glass Fiber reinforced polyester composites.

2. Materials and Methods

2.1. Specimen Materials

The materials used for the preparation of the composite were: unsaturated polyester resin (matrix), methyl ethyl ketene peroxide (catalyst), cobalt naphthalene (accelerator), Vaseline (releasing agent) were bought from local market. Glass fiber was obtained from local market in Kaduna. The empty banana bunch fiber was extracted from banana which was bought in Sabo market, Kaduna state, Nigeria. The palm oil fruit were obtained from Enugu state, Nigeria, thereafter, its fiber was extracted.

2.2. Equipment

The equipment used include: the metal mould, hydraulic press, Hounsfield Tensometer type 'w's/no 9875 UK (tensile test), Universal testing machine (flexural), Charpy impact testing machine HD9 6QD (Capacity 15J to 25J), Hardness Testing machine (Indenter Universal Hardness Machine 8187.5LKVModel B) grinding machine, Oven model OV-420 by Gallankamp, Sieve by ASTM, Electrically powered laboratory grinding mill, and two roll mill machine.

2.3. Composite Preparation

Preparation of the palm oil empty fruit bunch fiber

The palm oil fruit was boiled for about 1hour, the oil and seed were separated from its fiber by pounding manually in a mortar. Thereafter, the fiber as shown in Figure 1 was washed thoroughly with water until the oil content was removed. It was then sun dried for 4 hours and impurities removed before it was finally grinded to fine powder and sieved as presented in Figure 2.

Figure 1. Palm oil empty fruit fiber

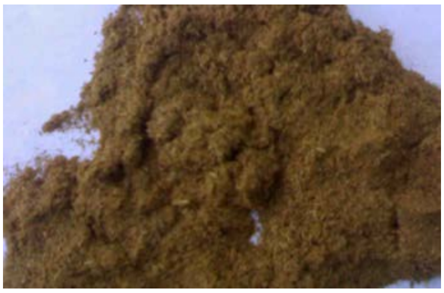

Figure 2. Palm oil empty fruit fiber grinded to fine powder

Extraction and chemical treatment of the empty bunch banana fiber

The fiber from the banana bunch (Figure 3) was extracted manually. The banana fibers (Figure 4) were washed using a clean tap water and sundried subsequently. Distilled water containing 6% NaOH was prepared. The sundried fibers were soaked in the NaOH solution for 4 hours 30 minutes. Thereafter, the fibers were removed and washed in running water and dried for 7 hours before it was used in the fabrication of the composite.

Figure 3. Banana empty fruit bunch

Figure 4. Banana empty fruit bunch fiber

Table 1. Sample Designation for the OPEFB -Banana-Glass Fiber Reinforced Polyester Based Composite

Composition (%wt)	Polyester (%wt)	Banana fiber(%wt)	Glass fiber(%wt)	OPEFB (%wt)
Polyester	100	-	-	-
Polyester/Banana fiber/OPEFB	75	20	-	5
Polyester/Glass fiber/OPEFB	75	-	20	5
Polyester/Banana fiber/Glass fiber/OPEFB	75	15	5	5
Polyester/Banana fiber/Glass fiber/OPEFB	75	10	10	5
Polyester/Banana fiber/Glass fiber/OPEFB	75	5	15	5

Table 1 shows the composition used in the manufacture of the composite.

The composite with fiber loadings of 5%, 10%, 15% and 20% volume fraction were fabricated using hand layup technique with a mould size of 120mm (length), 15mm (width) and 5mm (thickness). Releasing agent (Vaseline) was smeared at the bottom and walls of the mould to allow easy removal of the composite. Thereafter, the calculated quantity of polyester resin, methyl ethyl ketone (catalyst) and cobalt naphthalene (accelerator) were added and the mixture was stirred manually for about 5minutes to create a homogeneous mixture. The chopped strand fibers were then impregnated with the matrix in a randomly distributed manner. The mixture was poured into the mould and rammed mildly for uniform settlement. Other samples were moulded using the composition presented in Table 1. A dead weight weighing about 20kg was placed on the mould to increase the compactness of the samples. The samples was removed from the mould after three hours and allowed to cure.

2.4. Physical Properties Test

The physical properties tested on the samples were as follows:

Density

The density of the composite was determined using the relationship below:

$$\rho = m / v$$

Where,
m= mass the fiber specimen (g)
v= volume of the fiber specimen (cm^3)

The masses, m, of the fibers were determined to the nearest 0.001g by using the Mettler Electronic top pan balance. The volume, of each fiber specimen was calculated by percentage mass of the total specimen mass.

Water Absorption test

The water absorption of the composite was determined using the relationship below:

$$\text{Water absorption} = \frac{w_1 - w_0}{w_0} \times 100\%$$

Where:
w_0 = the weight of the specimen before immersion,
w_1 = the weight of the specimen 8hrs after immersion in water.

2.5. Mechanical Properties

Hardness test

The hardness test was carried out to measure the degree to which the material resists scratch, cutting, or indentation.

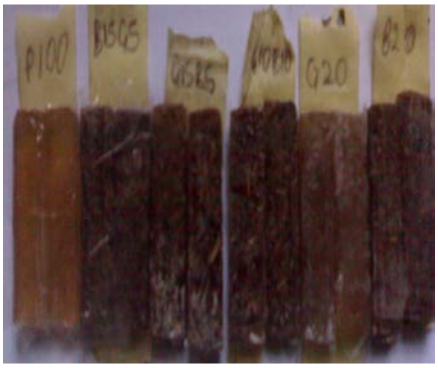

Figure 5. Hardness Test specimens

Figure 6. Micro Vickers Hardness Tester

The samples used for the hardness test is shown in Figure 5 A piece was cut from each sample and was placed on the machine; the hardness test was carried out at three different spots on each sample. The test was taken on two different points on each sample and the average hardness of the points was recorded using the micro Vickers hardness tester presented in Figure 6.

Tensile Test

The tensile test was performed on flat specimens. The dimension of the specimen was 120mm × 15mm × 5mm and a uniaxial load was applied on both ends. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. In the present work, this test was performed using the Hounsfield Tensometer (Figure 7) at a crosshead speed of 5 mm/min and the results were used to calculate the tensile strength of composite samples presented in Figure 8. The loading arrangement is shown in Figure. Here, the test was repeated three times on each composite type and the mean value was reported as the tensile strength of that composite.

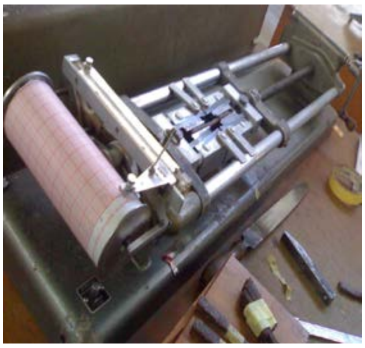

Figure 7. Hounsfield Tensometer

Figure 8. Tensile Test specimens

The tensile strength and tensile modulus were expressed as:

$$\text{Tensile strength } (\text{MPa}) = \frac{P}{bh} \tag{1}$$

$$\text{Tensile modulus } (\text{MPa}) = \frac{\sigma}{\varepsilon} \tag{2}$$

where,
P = pulling force (N)
b=specimen width(mm)
h= specimen thickness (mm)
σ =stress (N/mm^2), ε = strain

Flexural Test

The flexural strength of a composite is the maximum tensile stress that it can withstand during bending (Figure 9) before reaching the breaking point. The three point bend test was conducted on all the composite samples according to ASTM D790 in the universal testing machine at a constant rate of 2mm/min. The dimension of each specimen was 120mm × 15mm × 5mm. Span length of 100mm are maintained. For both flexural strength and flexural modulus, the test was repeated three times for each composite type and the mean value was reported.

The flexural strength and flexural modulus were calculated using the following equations.

$$\text{MOR } (\text{Flexural strength}) = \frac{3PL}{2bh^2}(\text{MPa}) \tag{3}$$

$$\text{MOE } (\text{Flexural modulus}) = \frac{mL^3}{4bh^3}(\text{MPa}) \tag{4}$$

Where,
P = maximum load applied on test specimen (N)
L = sport span (mm)
B = width of specimen tested (mm)
H = thickness of specimen tested (mm)
m = slope of tangent to the initial straight line portion of load deflection curve (N/mm)

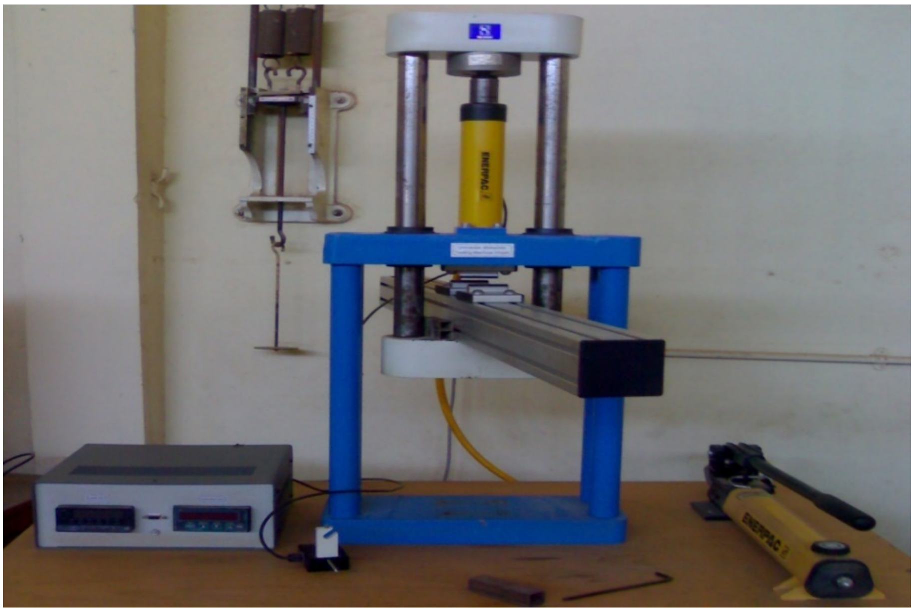

Figure 9. Flexural testing machine

Impact Test

The test was conducted in accordance with ASTM D 256 using Avery Denison test machine (Figure 10). Charpy impact tests were conducted on notched samples. Low velocity instrumented impact tests were carried out on the composite specimens. Standard un-notched rectangular impact test sample of measuring 120mm × 15mm × 5mm were used. Before the test samples were tested, the machine was calibrated. The test samples were then gripped horizontally in a vice and the force required to break the bar was released from the freely swinging pendulum. The value of the angle through which the pendulum has swung before the test sample was broken corresponded with the value of the energy absorbed in breaking the sample (Figure 11) and this was read from the calibrated scale on the machine.

Figure 10. Impact testing machine

Figure 11. Impact Test Specimens

$$\text{Impact strength} = \frac{J}{A}\left(\mathrm{J/m^2}\right) \qquad (5)$$

Where,
J = Energy absorbed (J)
A= Area of cross section of the specimen (m^2)
(b) Loading arrangement for tensile test
(a) Avery Denison test machine.

3. Results and Discussion

3.1. Density

Figure 12 shows the densities of the samples. It was found that Banana fiber 15%/Glass fiber 5% and Banana Fiber 20% had densities of 1.5123g/cm^3 and 1.5333g/cm^3, respectively. The density of glass fiber is more than the density of banana fiber. However, the banana fiber has more affinity to water molecules than glass fiber hence, the possible reason for the variation in densities. Their increase in densities is as a result of increase in water absorption and the inherent properties of the composite ingredients. The result also shows that the density of the samples increased significantly with increase in banana fiber.

3.2. Water Absorption

Figure 13 shows the percentage water absorption of the samples. It was found that Banana fiber15%/Glass fiber 5% had 4.19% water absorption and this was closely followed by banana fiber 20% with water absorption on 4.12%. As earlier asserted the figure shows that there was an increase in water absorption rate with increase in banana fiber. Hence, when the composite is exposed to moisture, the banana fiber composite might swell up a bit. The swelling could lead to the formation of micro cracking in the composite. As the absorption increases, the crack increases, eventually, capillarity and transport via micro cracks becomes active and water molecule flow along the fiber matric interfaces. This could eventually result in weakening the strength of the fiber and matrix.

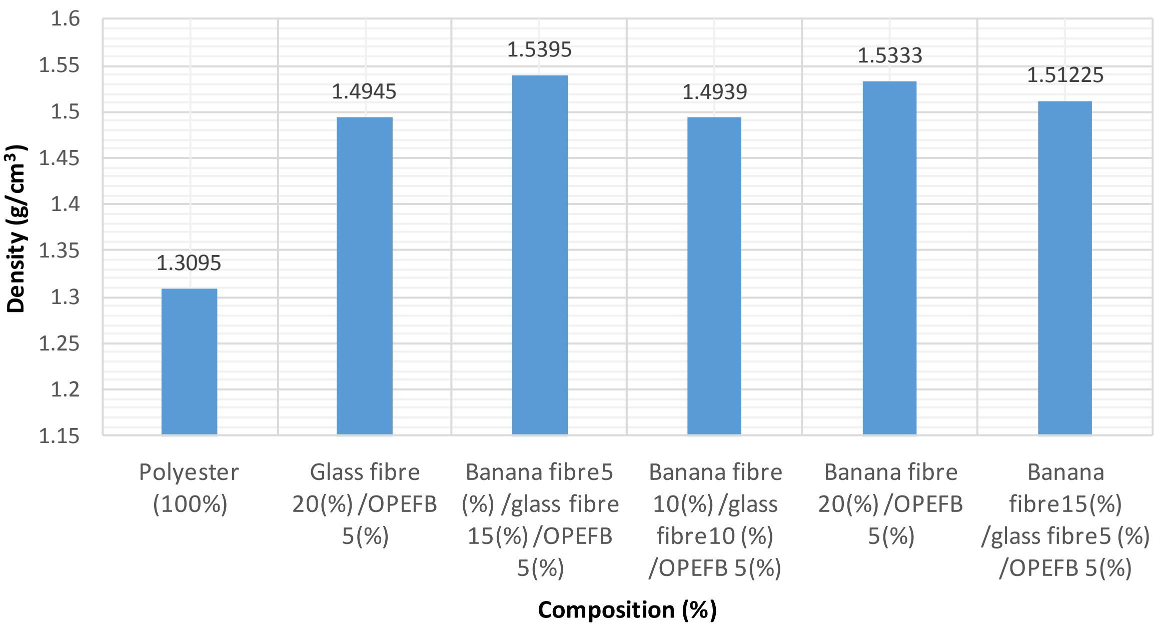

Figure 12. Density Test Values for banana and glass fiber polyester composite

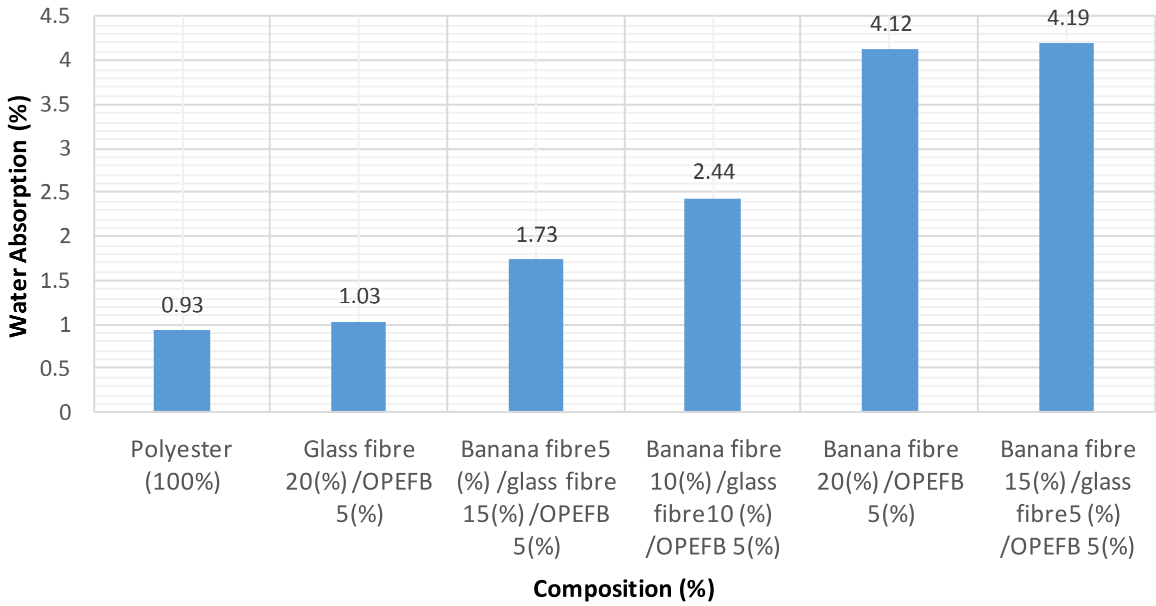

Figure 13. Water absorption Test Values for banana and glass fiber polyester composite

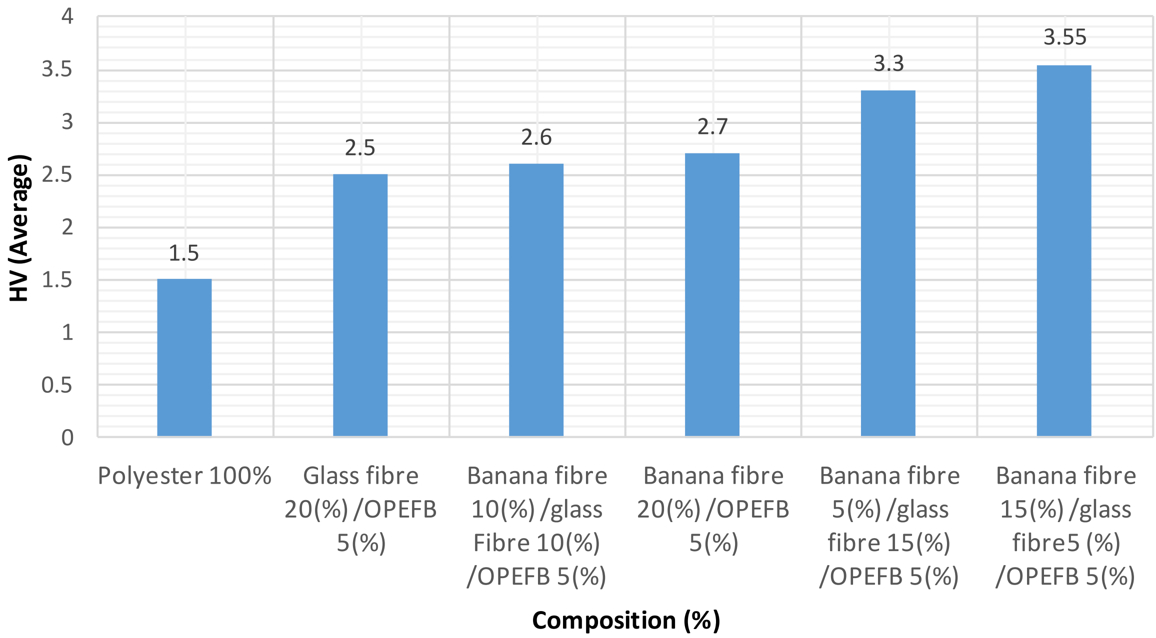

Figure 14. Hardness Test Values for banana and glass fiber polyester composite

3.3. Hardness

Figure 14 shows the mean hardness values of the specimens. The hardness of the samples was influenced by a considerable increase in banana fiber content in the composite. For instance, it was found that banana fiber15%/glass fiber 5% hybrid composite has the highest hardness (3.55HV representing 136.67% improvement on the hardness of the polyester (1.5HV). The improvement in the hardness of the composite material could lead to reduction in wear rate when in service. A careful examination of the results shows that banana-glass hybrid composite showed better hardness than composite that consisted individually of banana fiber and glass fiber with a constant percentage of OPEFB.

3.4. Impact Strength

The impact strength of a material is the measure of the amount of energy which the material can absorb before its failure. The impact test was therefore carried out in order to analyse the impact strength of the specimens. From Figure 15, the relationship between the average energy and impact strength of the composites is clearly shown. Banana10%Glass10% hybrid composite has the highest impact strength (55.556 J/m^2), which was followed by Glass15%Banana5% with impact strength of 24.556 J/m^2. This value was greatly influenced by the percentage of glass fiber in the composite because of its toughness; glass fiber has a higher resistance to impact force. In parts where high impact strength is required the exploitation of 50:50 mixtures of hybrid banana fiber and glass fiber could be considered. This will lead to the utilization of more environmentally friendly and sustainable materials such as banana fiber.

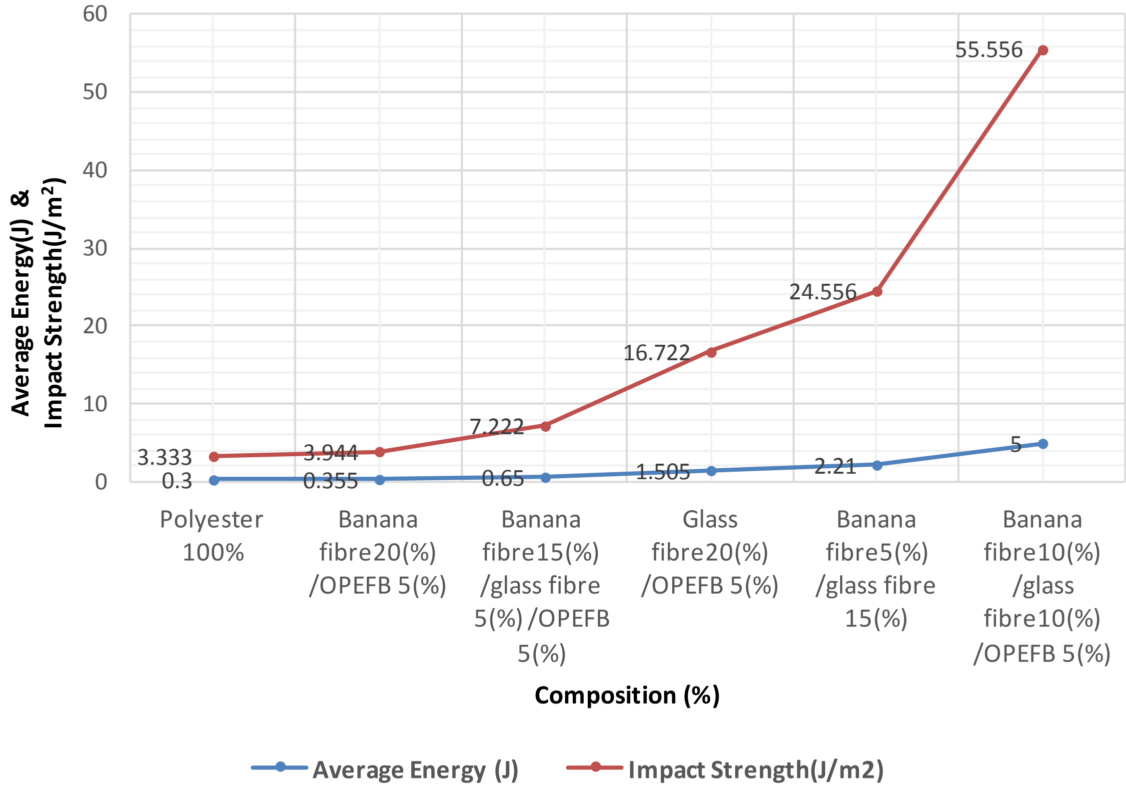

Figure 15. Impact Test Values for banana and glass fiber polyester composite

3.5. Flexural Strength

Figure 16 shows the mean loading and flexural strength values for the various composites. It could be seen that the Banana fiber 20% with 5% OPEFB composites presented the lowest flexural strength of 18.51Mpa before failure, while banana fiber5%/Glass fiber15% had 44.84Mpa before failure composites showed the highest results and, is closely followed by Glassfiber20% with 36.72Mpa. It was observed that as the banana fiber content increased there was a decline in the flexural strength. However, increasing the glass fiber content resulted in corresponding increase in flexural strength. Under flexural loading, the upper and lower surfaces of the specimen are subjected to higher deformation than the mid-plane. Therefore, flexural strength and stiffness depends on the properties of the surface layers. Therefore, glass fiber has greater flexural strength than banana fiber.

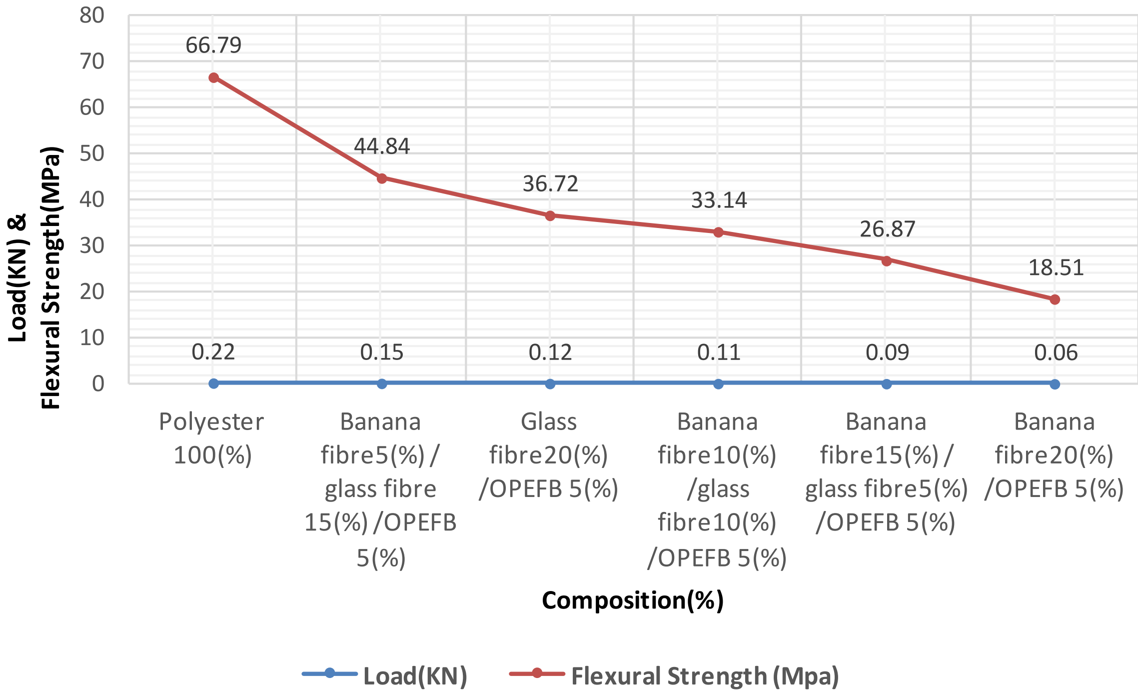

Figure 16. Flexural Test Values for banana and glass fiber polyester composite

3.6. Tensile Strength

The tensile property of the unreinforced specimen sample was 15.05 MPa. Figure 17 shows the extension, strain and tensile strength of the specimens. Glass fiber had the highest extension, strain and tensile strength of 6.72mm, 0.056J and 24.66MN/mm^2 (77.14% improvement over the virgin polyester tensile strength), respectively. This was closely followed by Banana fiber 5%/Glass fiber15% hybrid composite with extension, strain and tensile strength of 6.5mm, 0.055J and 24.35MN/mm^2 (61.79% improvement over the virgin polyester tensile strength), respectively. The tensile strength of the composite depends to a large extent on the interfacial bonding strength between the matrix, reinforcement and fillers and also on the inherent properties of the composite ingredients. Improvement in tensile strength of composite helps the composite to withstand more tensile forces when they are in service. Also, materials with more strain are likely to fail safe in service

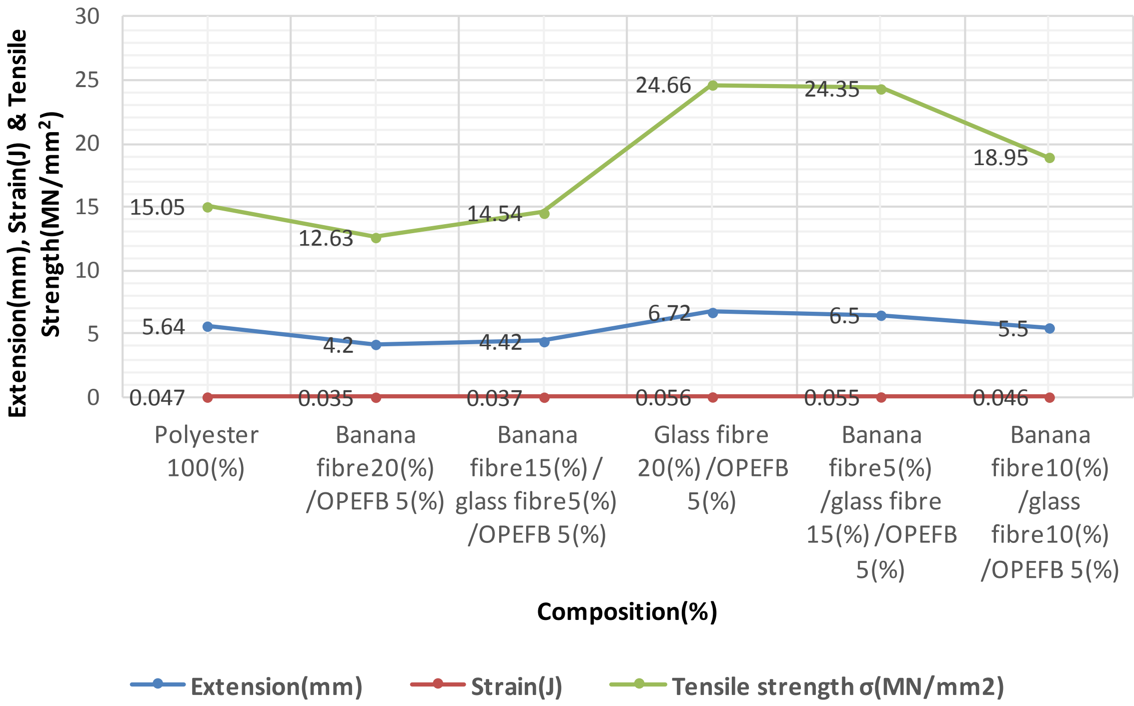

Figure 17. Tensile Test Values for banana and glass fiber polyester composite

4. Conclusions

From these results the following conclusions were drawn:

1. The water absorption of composite with greater banana fibers was higher than that of glass fibers. However, the density of glass fiber composite was more than that of the banana fiber.
2. Glass fiber had better tensile strength than banana fiber in the composite.
3. It was observed that as the banana fiber content increased, there was a decline in the flexural strength. However, increasing the glass fiber content resulted in corresponding increase in flexural strength.
4. Impact strength of banana fiber 10(%) /glass fiber10(%) composite was quite high with impact strength of 55.556J/m^2 (representing 1568.67% improvement over that of the virgin polyester) when compared with the other composites.
5. It was found that banana fiber15%/glass fiber 5% hybrid composite had the highest hardness (3.55HV representing 136.67% improvement on the hardness of the polyester (1.5HV). Hardness of the samples was influenced by a considerable increase in banana fiber content in the composite
6. Banana composite could be considered for applications where high impact strength is a requirement such as in some parts of automobile, aircrafts, etc.

References

[1] Mallick P.K.: Fiber-reinforced composites. In: Materials, manufacturing and design. New York, NY: Marcel Dekker, Inc; (1989).

[2] Venkatasubramanian, H., Chaithanyan, C., Raghuraman, S. and Panneerselvam, T.: Evaluation of mechanical properties of abaca-glass-banana fiber reinforced hybrid composite, International Journal of Innovative Research in Science, Engineering and Technology, 3, 1, (2014).

[3] Bledzki A.K. and Gassan J.: Natural fiber reinforced plastics. In Handbook of engineering polymeric materials., Nicholas P., Cheremisinoff ed., CRC Press, New York, Chapter 52, 787 (1997).

[4] Samivel, P. and Babu, A.R.: Mechanical behaviour of stacking sequence in kenaf and banana fiber reinforced-polyester laminate. International Journal of Mechanical Engineering and Robotics Research. 2, 4, 348-360, (2013).

[5] Dharmalingam, T. G.and Raj, P. P.: Study of mechanical properties of banana-coir hybrid composite using experimental and fem techniques. Journal of Mechanical Engineering and Sciences (JMES), 4, 518-531, (2013).

[6] Soma Dalbehera S. and Acharya K.: Study on mechanical properties of natural fiber reinforced woven jute-glass hybrid epoxy composites. Advances in Polymer Science and Technology, 4 (1), 1-6, (2014).

[7] Herrera-Franco P.J. and Valadez-Gonzalez.: A study of the mechanical properties of short natural fiber reinforced composites. Composites B, 36, 597-608, (2005).

[8] Sanadi A., Caulfield D.F. and Jacobson R.E.: Paper and Composites from Agro-based Resources, Lewis Publishers, New York (1997).

[9] Manikandam Nair K.C., Thomas S., and Groeninckx G.: Thermal and dynamic mechanical analysis of polystyrene composites reinforced with natural fibers. Composite Science and Technology, 61, 2519-2529, (2001).

[10] Rozman H. D., Mohd Ishak Z.A., and Ishiaku U.S.: in Natural Fibers: Biopolymers and Biocomposites, A. Mohanty, M. Misra and L.T. Drzal, Eds., Taylor and Franscis, Boca Raton, 407 (2005)

[11] Singh V. K., Gope P. C., Chauhan S. and Singh B. D.: Mechanical behavior of banana fiber based hybrid bio composites, J. Mater. Environ. Sci. 3 (1), 185-194, (2012).

[12] Pothan L.A., Thomas S. and George J.: Tensile and impact properties of banana fiber/glass fiber hybrid polyester composites, www.iccm-central.org/proceedings/iccm12proceedings/.../pap1267.pdf.

[13] Rajesh Ghosh., et. al.: Effect of fiber volume fraction on the tensile strength of banana fiber reinforced vinyl ester resin composites. 4, 1, 08-091, (2011).

[14] Sumaila M., et. al.: Effects of fiber length on the physical and mechanical properties Of random oriented, nonwoven short banana (Musa Balbisiana) fiber / epoxy composite, Asian Journal of Natural and Applied Sciences, 2, 1, 39, (2013).

[15] Ashwani Kumar and Deepak Choudhary: Development of glass/banana fibers reinforced epoxy composite. International Journal of Engineering Research and Applications 3, 6, 1230-1235, (2013).

[16] Valadez-Gonzalez, J.M., Cervantes-Uc., Olayo R., and Herrera – Franco P.J.: Effect of fiber surface treatment on the fiber-matrix bond strength of natural fiber reinforced composites. Composites Part B: engineering, 30(3), 309-320, (1999).

[17] Sreenivasan S., Bhama Iyer P., and Krishna Iyer K.R.: Influence of delignification and alkalis treatment on the fine structure of coir fibers (cocos nucifera). J. Mater. Sci. 31, 721-726 (1996).

[18] John M.J., Francis B., Varughese K.T. and Thomas S.: Effect of chemical modification on properties of hybrid fiber bio composites. Composite. Part A: Applied Sci. Manuf., 39 : 352-363, (2008).

[19] Sreekala M. S., Kumaran M.G., Geethakumariamma M.L. and Thomas S.: Environmental effects in oil palm fiber reinforced phenol formaldehyde composites: studies on thermal, biological, moisture, and high energy radiation effects, Adv. Compos. Mater. 13, 171-197, (2004).

[20] Rozman H.D., Lai C., Ismail H. and Ishak Z.A.M.: The effect of coupling agents on the mechanical and physical properties of oil palm empty fruit bunch – propylene composites. Polym. Int., 49: 1273-1278, (2000).

[21] Sain M., Suhara P., Law S., and Bouilloux A.: Interface modification and mechanical properties of natural fiber-polyolefin composites products. J. Reinf. Compos 24(2), 212-130, (2005).

[22] Morena J.J.: Advanced composite mold making, New York; Van Nostrand Reinhold Co. Inc., 124-125, (1988).

[23] Bastra S.K.: in Handbook of fiber chemistry, Lewin M. eds., CRC Press, Taylor and Francis, Boca Raton, 453, (2007).

[24] Jon Soller.: Choosing the appropriate resins – epoxy versus vinylester versus polyester resins; Soller composites, 1-5, (2004).