



ORIGINAL RESEARCH ARTICLE

EFFECT OF PARTICLE AND FIBER LOADING ON TENSILE, FLEXURAL AND IMPACT PROPERTIES OF HYBRIDIZED BALANITE SHELL PARTICLES AND PALMYRA FIBER REINFORCED EPOXY COMPOSITE

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ABSTRACT

The new trend of using natural fibers and fillers has greatly improved the formulation of composites. It has been established over the years that natural fibers and fillers have the required characteristics to reinforce polymers. In this study, Palmyra fiber and Balanite shell particles were used to reinforce epoxy $C_{28}H_{30}O_2$. Palmyra fiber and Balanite shell particles together formed the reinforcement having equal weight percentage of 50:50. The particle size of the Balanite was $150\mu m$ while 90 mm length of the Palmyra fiber was utilized. The compounding ratio of reinforcements to epoxy was 10:90, 20:80, 30:70, 40:60 and 50:50 respectively in order to see the effect of reinforcements loading of the Epoxy on the hybrid composite's mechanical properties. Palmyra fiber was treated with 5% NaOH solution before compounding in order to improve fiber-particle-matrix adhesion. The composite was formulated based on the mixing plan using hand lay-up method which was followed up by a compression molding operation at 2.5 MPa of pressure in order to have good compaction of the composite and further matrix distribution. These formulated composites were named Balanite Palmyra Epoxy (BPE), that is, BPE1, BPE2, BPE3, BPE4 and BPE5 with the numbers describing weight percentage loading of reinforcements of 10, 20, 30, 40 and 50 respectively. Characterization of the composites were done to determine their tensile strength, flexural strength and impact strength. Scanning electron microscopy (SEM) was also carried out in order to know the interaction of the matrix and reinforcements. BPE3 with 30% reinforcement was found to have had the highest tensile strength of 52.99 MPa from 30 MPa of the pure Epoxy, resulting in 44% improvement of the tensile property of the matrix with elongation at break gradually dropping with material loading as a result of reduced flexibility of the matrix resulting from interruptions of its extension by the reinforcements; impact strength of 0.494 J/mm was obtained which gave about 63% improvement of the matrix. BPE2 with 20% reinforcement gave the highest flexural strength of 141.2 MPa and presented an improved flexural property of the matrix by 34%. Tensile modulus increased with reinforcements loading while flexural modulus dropped after 20% loading mainly because of the brittle nature of the matrix. The properties obtained from the hybrid composite make it suitable for low to medium load applications.

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1.0 Introduction

In our world today, there is a great need to free our environment from unused waste products scattered around. It is very important to achieve proper utilization of waste products, creating an environment that is free of hazards and making it possible to convert wastes to manageable business in order to solve the problem of unemployment and generate money. Currently, significant efforts are being invested in the pursuit of a

better production and proper utilization of natural fibers to make good composites that will stand worthy of use in different areas of application. Epoxies have been used widely as adhesives, coatings and also as electronic materials. They also serve as matrices for fiber-reinforced composites. They possess unique mechanical properties which include, high adhesive strength, good heat and electric resistance (Hsissou *et al.*, 2019). Natural fiber is a good and renewable type of reinforcement. It can also be considered as reinforcement for polymeric materials. The inclusion of natural fiber in polymeric materials is considered to be an environmentally friendly activity and it has been a trending topic recently because of the attention given to the environment. This is worthwhile because of their advantages over synthetic fibers such as low cost, low weight, minimal damage to processing equipment, great surface finish, good mechanical properties and also, availability (Lotfi *et al.*, 2021).

Balanite shell particles are gotten from *Balanite aegyptiaca* (L.), which belongs to the zygophyllaceae family, native to Africa and is found in tropical and subtropical parts of Africa, mostly used for medicinal purpose. The shell of the fruit is usually thrown away leaving behind a problem of unused resources and dirty environment. These desert dates found in most of the states of Northern Nigeria are cheap and abundant (Murthy *et al.*, 2020). Palmyra fiber is gotten from Palmyra fruits also known as Borassus Flabellifer. This is also found in most parts of Africa and Asia and it belongs to the family (Arecaceae). It is found in great quantity in the Northern States of Nigeria. The tree produces fruits twice in a year. Palmyra has natural long fibers which are always available, eco-friendly and are renewable in their behavior (Srinivasababu *et al.*, 2014). The fruit contains the succulent watery part engulfing the fiber. The nice-smelling succulent part is eaten while the fiber is thrown away as waste.

Sathishkumar *et al.* (2022) gave a comprehensive analysis on the synthesis and mechanical properties of natural fiber reinforced epoxy/polyester/polypropylene composites using different natural fibers and methods that includes hand lay-up. they observed that there was a decrease in tensile strength of the natural fibers with respect to cellulose removal. On the other hand, Vengaiah *et al.* (2021) studied some physical properties of Palmyra fiber. The fibers were gathered, washed, soaked in an alkaline solution at 70% (NaOH) and then dried under the sun. The palmyra fruit pulp percentage ranged from 21.67 to 56.67% with the average value 37.82%, nut percentage ranges from 27.78 to 58.33% with the average value 46.06%, and sheet/fiber percentage ranged from 9.82 to 20% with the average value 16.12% as given. The coefficient of friction ranged from 0.27 ± 0.04 . These values indicate the viability of Palmyra fiber in composite formulation. Kai Zhang *et al.*, (2018) investigated the thermal stability of a bamboo fiber reinforced epoxy composite and also checked the suitability and appropriate concentration of NaOH for bamboo fiber treatment. fibers treatment with 2 wt.%, 6 wt.% and 10 wt.% NaOH solutions for 12 hrs were conducted and Hand lay-up technique was used for the fabrication of the composites using Epoxy as the matrix material. They concluded that the fibers that were treated with 6 wt. % NaOH demonstrated improved tensile properties and bonding with epoxy which also gave an improved thermal characteristic. Parbin *et al.* (2019) reviewed mechanical properties of natural fiber reinforced epoxy composites and concluded that natural fiber composites exhibit best tensile, flexural and impact properties. Furthermore, lower concentration of NaOH gave better tensile strength and hardness. Ram *et al.* (2018) studied the dynamic mechanical properties of Asian palmyra sprouts fiber reinforced epoxy composites by using the hand lay-up method to prepare the composite after 1% of NaOH solution treatment of the fiber. It was concluded that the dynamic mechanical properties of Asian Palmyra fiber reinforced epoxy composites were greatly dependent on the percentage of fiber loading. In another study, (Rizal *et al.*, 2018) studied the crystalline Structure, morphology, Wettability, Interfacial Shear Strength, tensile, flexural and impact strength of Typha fiber reinforced epoxy composite. The composites were prepared using the hand lay-up technique after soaking the fiber in 5% NaOH solution. It was concluded that NaOH successfully eliminated lignin and celluloses from the fiber and the tensile, flexural, interfacial shear strength and impact strength of the Typha fiber reinforced epoxy composite were increased. The improved mechanical properties were due to the better interfacial compatibility between the alkali treated Typha fiber and epoxy resin. Ganapathy *et al.* (2021) studied the effect of graphene powder on banyan aerial root fibers reinforced epoxy composites. Epoxy resin (Araldite LY 556) of density 1.2 g/cc and hardener (Aradur HY 951) of density 0.98

g/cc were used. The long fiber was soaked in 5% NaOH solution for 2hrs and then washed with tap water to remove NaOH from the surface of the fibers. The result showed good improvement in mechanical properties. However, high rate of water absorption was observed due to the hydrophilic nature of the fibers.

The major challenges in solid waste management include waste generation, poor collection of waste, poor treatment and disposal processes (Soni *et al.*, 2022). The demand of the manufacturing industry for newer and better materials keeps increasing and this leads to constant efforts to satisfy this demand. The composite that is made up of Palmyra fiber, Balanite shell particles and epoxy resin can be applied to many automobile components and building materials because of its good mechanical properties that closely relates to most automobile interior components. It is a demonstration of improving thermoset composites that are eco-friendly from a socio-economic point of view. Using natural fibers such as Borassus flabellifer, Flax, Sisal, Jute and Kenaf to replace synthetic fibers in composite formulation has been on the increase but the matter of compatibility has to be taken seriously with the matrix in mind (Dinesh *et al.*, 2015) and Aji *et al.* 2011). However, modifications can also be done either by physical or chemical treatment to make natural fiber reinforced composites suitable for specific uses (Rohan *et al.*, 2018). This work developed a hybrid composite from the combination of particle and fiber to reinforce Epoxy matrix.

2. Materials and Methods

2.1 Materials

The raw materials used for this work were Palmyra fiber, Balanite shell particles, Epoxy resin, Distilled water and 5 mol of sodium Hydroxide (NaOH).

Palmyra fruits were purchased from a Palmyra farm in Kaltungo, Gombe state, Nigeria. Balanite fruits were purchased in Maiduguri Monday market, Nigeria and Epoxy resin $C_{28}H_{30}O_2$ was purchased from E.B POLY Company, Gombe State - Nigeria.

2.2 Equipment

The equipment used for this work are presented in Table I.

Table I: Equipment and Specification

S/N	Equipment	Purpose	Model
1	Universal Testing Machine	Tensile/Flexural Test	D-100KN (SN:190536)
2	Hammer Mill	Grinding of Balanite	MB11C
3	Metal Mold Box	Composite Structure	180mm×180mm×3.2mm
4	Standard sieve	Sieving of Particles	150µm
5	Resil Impact Tester	Impact Test	Resil (695-0000)
6	Scanning Electron Microscope	SEM Test	JSM IT 700HR
8	Digital weighing Balance	Weighing of Samples	Mettler

2.3 Preparation of Balanite Shell Particles

Balanite shells were separated from their fruits by pressing them manually with the hand. The separated shells were washed thoroughly with water and dried under the sun for 48hrs. After drying, they were ground into particles using a hammer mill and then sieved with a standard sieve of 150 μ m because smaller particles perform better as a result of better compaction (Lawal *et al.*, 2017). Figure 1 presents the Balanite shell particles.



Figure 1: Balanite Shell Particles

2.4 Preparation and Treatment of Palmyra Fiber

Palmyra fruits (Figure 2a) were gotten from a Palmyra farm in Kaltungo, Gombe State, Nigeria and washed with hot water combined with (NaCl) then rinsed in water to remove greater amount of the pulp. The fiber (Figure 2b) was cut with the aid of a sharp knife into uniform length of 90 mm because of the need for longer fiber in hand-lay-up process. It was allowed to dry under the sun for 48 hrs. Palmyra fiber was plunged into a solution containing 5% NaOH for 1hr to enhance adhesion between the matrix and fiber by exposing the fiber interlocking surfaces (Reddy *et al.*, 2020). This will help to improve the interfacial fiber and matrix bonding. The fiber was washed repeatedly with distilled water so that it would be free of alkali used for its treatment. The fiber was tagged alkaline free after indicating a PH value of 7.0.



Figure 2 (a and b): Palmyra Fruit and Fruit Fiber

2.5 Preparation of Composite

2.5.1 Compounding

The Balanite shell particles were utilized with Palmyra fiber at 50:50 percent weight ratio ranging from 10-50%. The Balanite shell particles and epoxy were mixed manually with a stirring rod for about 20 minutes to achieve a homogenous state (Lawal *et al.*, 2017). The composites were named BPE (Balanite, Palmyra and Epoxy) for easy identification. Table 2 presents the mix ratio and formulation utilized for this work.

Table 2: Mix Ratio of Epoxy, Palmyra Fiber and Balanite Shell Particles

Sample	Balanite and Palmyra(50:50 % weight)	Epoxy Resin (% weight)
Control (100% Epoxy)		
BPE 1	10%	90%
BPE 2	20%	80%
BPE 3	30%	70%
BPE 4	40%	60%
BPE 5	50%	50%

2.5.2 Hand Lay-up

Hand lay-up method accompanied by compression moulding was used to prepare the hybrid composite. A mold of 180mm×180mm×3.2mm was used and a resin repellent material was spread on the surface of the mold to avoid adhesion between the mold and the composite after curing. The first layer of epoxy resin and Balanite shell particles mixture was spread at the base of the mold and Palmyra fibers were arranged and uniformly distributed to the different parts of the already spread epoxy and Balanite shell particles mixture. Mixture of epoxy and Balanite shell particles was spread again on the arranged Palmyra fibers. This process was carefully repeated until the desired thickness was achieved. A pressure of 2.5 MPa was applied on the mold by a compression molding machine to exert pressure on it allowing its cure for 24hrs (Ram et al., 2018).

2.6 Characterization of the Hybrid Composites

2.6.1 Determination of Tensile Strength

The tensile strength test was conducted according to ASTM D-638 by using a universal testing machine with a testing speed of 5mm/min and sample dimension of 165mm×19mm×3.2mm. The samples were subjected to tensile force with both ends clipped to the testing machine till failure was observed on the sample and the failure load was recorded. Tensile strength, tensile modulus and elongation at break were generated automatically by the machine.

2.6.2 Determination of Flexural Strength

Flexural test was carried out in the department of mechanical engineering workshop, Ahmadu Bello University, Zaria according to ASTM D-790 with sample size of 100mm×25mm×3.2mm. The samples were placed horizontally at 80mm gauge length on a support pan. Using a Hounsfield Monsanto Universal Testing Machine, load was applied to the center producing bending (three-point bending) at a specified rate until there was failure in the specimen. The UTM documented the result up to when the sample failed. Readings of the maximum load (N) and the deflection (mm) were taken.

2.6.3 Determination of Impact Strength Properties

Impact strength test was carried out in accordance to ASTM D-256. CEAST Resil impact testing machine (6957.0000) was used to conduct the test. The dimensions for the specimens were 64mm×12.7mm×3.2mm. A hammer, weighing 1500 N was inclined at an angle of 150° and released on the specimen. Specimen was vertically clamped on the jaw of the machine and notched at an angle of 40°. The load that resulted to a failure was recorded as the impact energy. This procedure was repeated five times and average value recorded. The impact strength was calculated using equation 1 as recommended by Koppula et al., (2018).

$$\text{ImpactStrength} = \frac{\text{AverageImpactEnergy}}{\text{SpecimenThickness}} \quad (1)$$

3. Results and Discussion

3.1 Tensile Strength

It can be seen clearly in Figure 3 that addition of Balanite shell particles and Palmyra fiber resulted to an increase in tensile strength of the composite. The minimum amount of reinforcement added to pure epoxy stepped up its tensile strength. This is similar to the result obtained in the investigation of Nurazzi *et al.* (2020) on the reinforcement of polyester with sugar palm yarn fiber. Initially the control sample had a tensile strength of 29.73 MPa and 10% of reinforcement improved the tensile property to 36.60 MPa. Furthermore 20% loading of the matrix increased the tensile strength to 47.60 MPa. The peak of tensile strength was gotten when the reinforcement reached 30% with a value of 52.99 MPa and further addition resulted in a slight drop to 51.01MPa at 40% reinforcement which dropped further at 50% loading. This drop in tensile strength at higher loading was due to inadequate wetting of the reinforcement by the matrix to cover the entire reinforcement and continue the distribution of load in the composite. BPE3 which has the highest tensile strength value improved the tensile strength of the matrix by 44%.

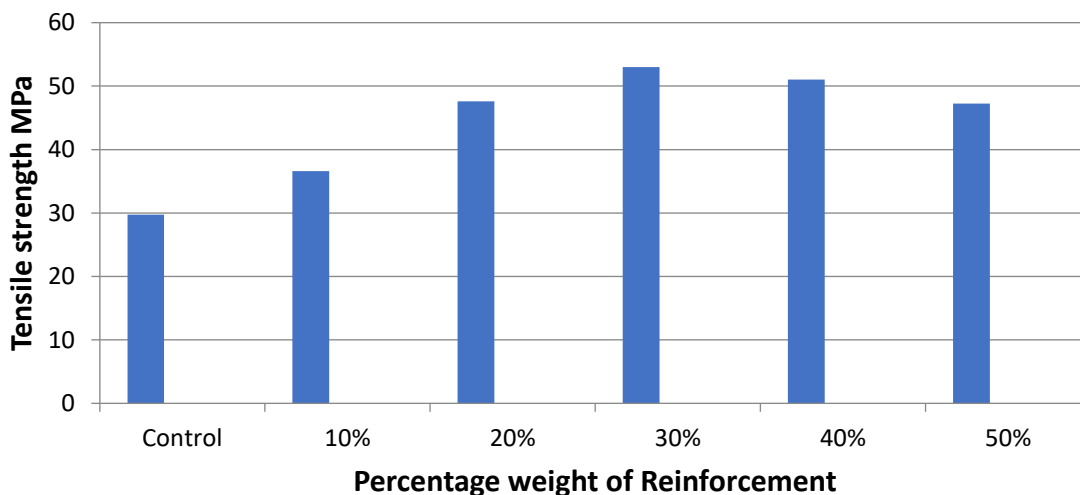


Figure 3: Effect of Reinforcement on Tensile Strength of BPE Composites

The result was further checked using the scanning electron microscopy and presented in Figure4 when the specimen, BPE3, failed during test. SEM showed a uniform Balanite and Palmyra fiber distribution at the top. The bottom region shows where the failure occurred and the Balanite shell particles were forcefully separated from Palmyra fiber. Delamination of the reinforcement increased stress distribution to different parts of the composite which resulted in failure. This also, is similar to the findings of Nurazzi *et al.* (2019).

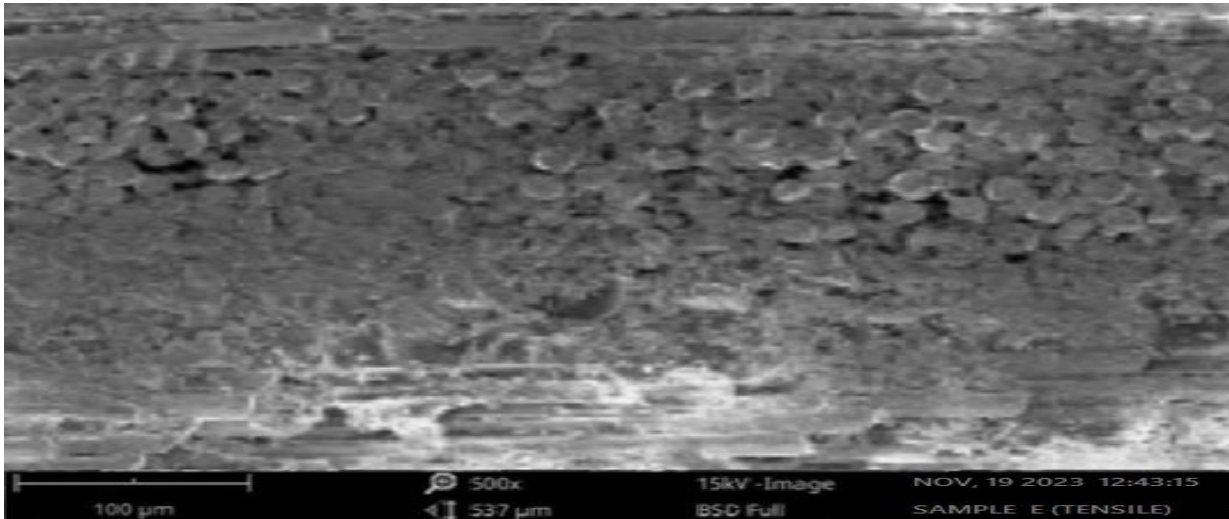


Figure 4: SEM of Failed BPE3 Tensile Strength Test Sample

3.2. Tensile Modulus

Figure 5 shows that the stiffness of the composite increased with increase in fiber loading as reinforcement increased from 10% to 30%. It can also be seen that the elastic modulus dropped slightly at 40% reinforcement. This drop could be due to poor adhesion between the fibers and matrix and also as a result non-uniform distribution of Balanite shell particles. This is similar to the result obtained by Nurazzi *et al.* (2020). However, the modulus remarkably increased at 50% loading to indicate the expected result of more cellulose in composite increases the modulus of composites.

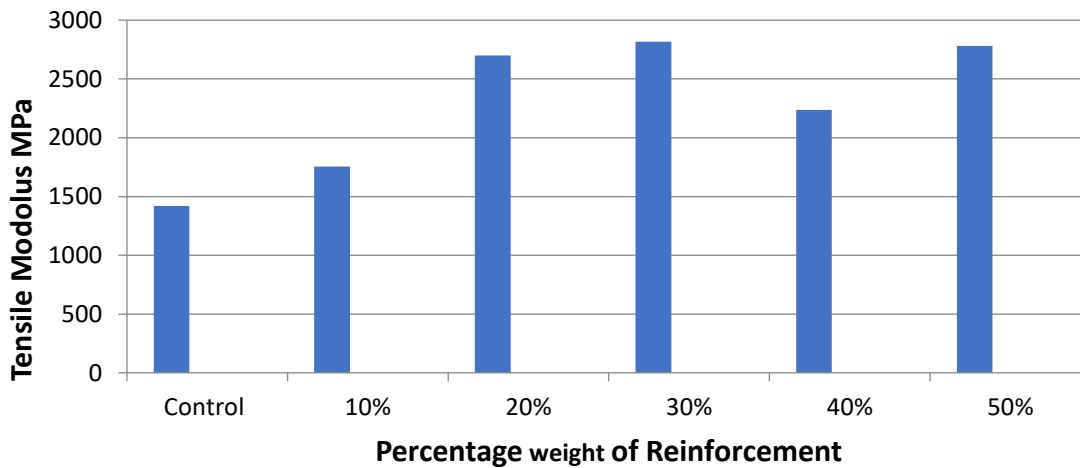


Figure 5: Effect of Reinforcement on Tensile Modulus of BPE composites

3.3 Elongation at Break

Figure 6 shows that elongation decreased as reinforcement increased. Epoxy was stretched to 5.26% but subsequent addition of reinforcement led to a direct proportionate decrease in elongation. The decrease in elongation is because the deformations of Palmyra fiber and Balanite shell particles are less than that of epoxy which made epoxy to deform at a smaller length than it normally should. Koyuncu and Erkek (2022) made the same observation in a study while reinforcing epoxy with walnut husk and pumice particles. Furthermore, the addition of filler led to a decrease in elongation at break because it made the composite more brittle that may likely be as a result of the brittle nature of epoxy.

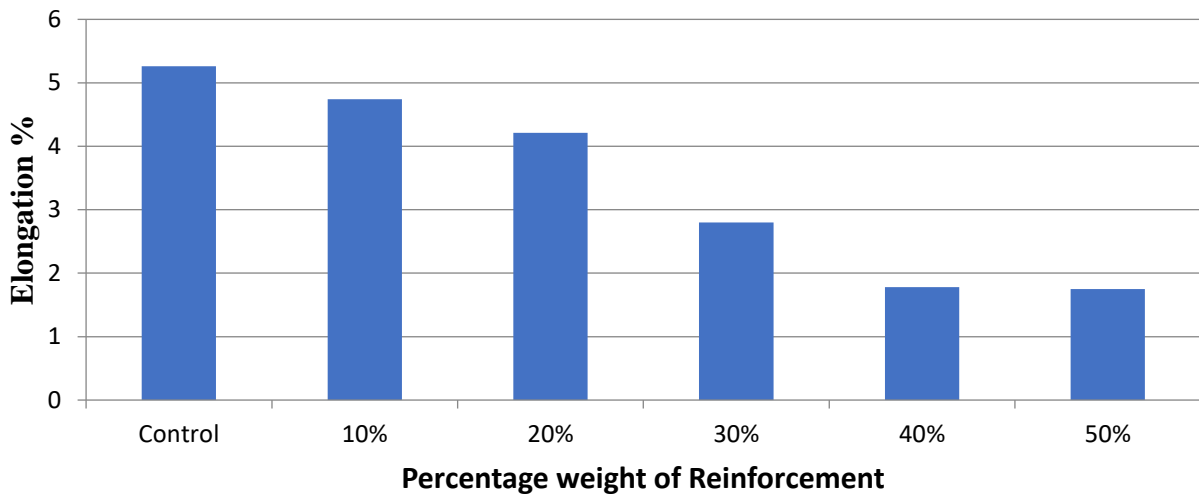


Figure 6: Effect of Reinforcement on Elongation of BPE Composites

3.4 Flexural Strength

Figure 7 shows the flexural strength test result of the Balanite shell particles and Palmyra fiber reinforced epoxy composite. The highest value of flexural strength, 141 MPa was obtained at 20% loading of reinforcements. It can also be noted that after obtaining the peak flexural value, there was a gradual decrease with respect to addition of reinforcement to 98.76 MPa 50%. This drop in flexural property is due to the formation of voids and poor bonding as reinforcement loading increased; this also affected the distribution of load from the matrix to the reinforcement. This flexural behavior of the composite is similar to what was obtained in the study conducted by Samuel *et al.* (2018). BPE2 with 20% reinforcement increased the flexural strength of the matrix by only 34%. This further confirm that the brittle nature of epoxy in combination with brittle reinforcements affected stress distribution even at lower loading which jeopardized getting better strength at higher material reinforcements.

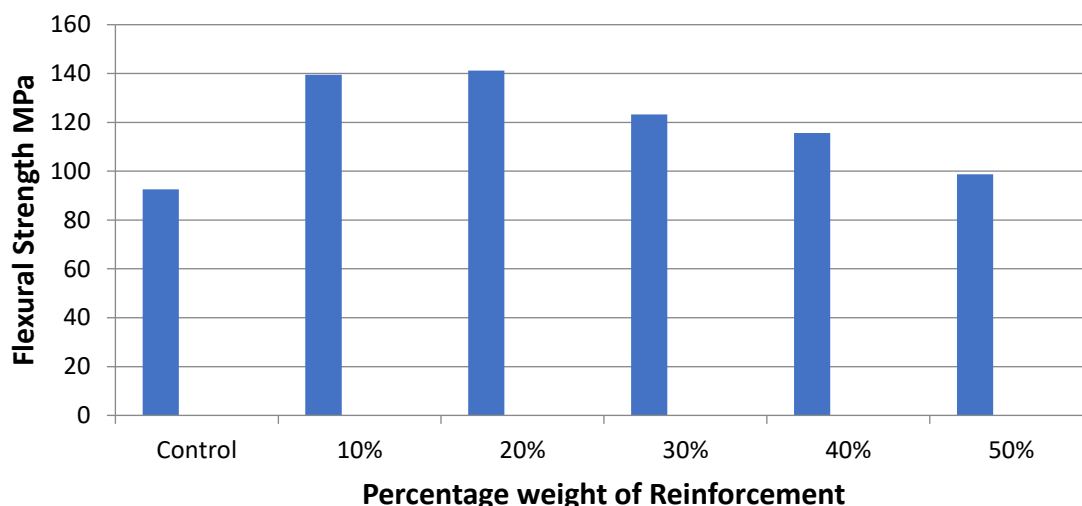


Figure 7: Effect of Reinforcement on the Flexural Strength of BPE composites

The SEM result with optimum value for flexural strength at 20% reinforcement loading shows that there was a homogenous matrix-fiber mix. Further addition of reinforcement led to reduction of flexural strength although the decrease was not abrupt. This is similar to the study conducted by Zin *et al.* (2019). The decrease in flexural strength could be due to higher fiber loading that resulted in fiber entanglement likely because of

the brittle nature of the matrix. This affected the flexural strength of the composite. From the SEM in Figure 8, fiber breakage can be seen at some points due to failure caused by the three-point bending forces even at lower stress.

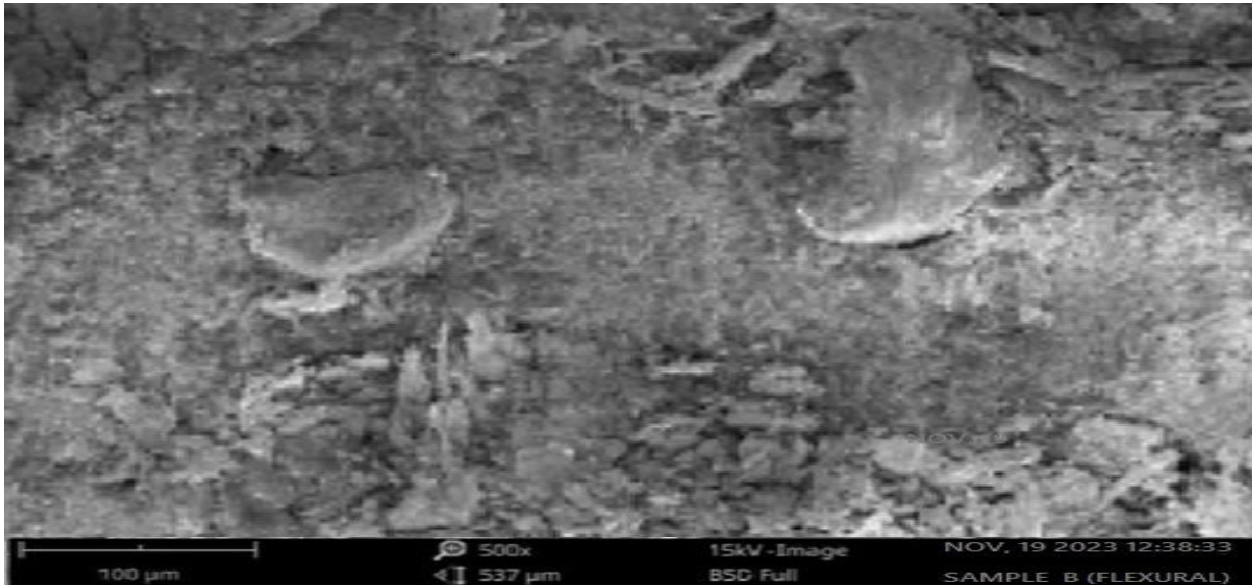


Figure 8: SEM Micrograph of 20% Reinforcement Flexural Strength Sample

3.5 Flexural Modulus

It can be seen in Figure 9 that flexural modulus increased with reinforcements up to the 20% reinforcement. A maximum of 8 GPa was obtained at the maximum positive reinforcement before it went through a gradual drop in modulus to about 3.528GPa at 50% loading. This result is similar to what Samuel *et al.* (2018) observed in a study in which Doum palm shell particles were used to reinforce Polypropylene. Further introduction of particle may have made the composite rigid and therefore blocking further stress distribution within the composite. This made fiber pullout very easy at higher material loading.

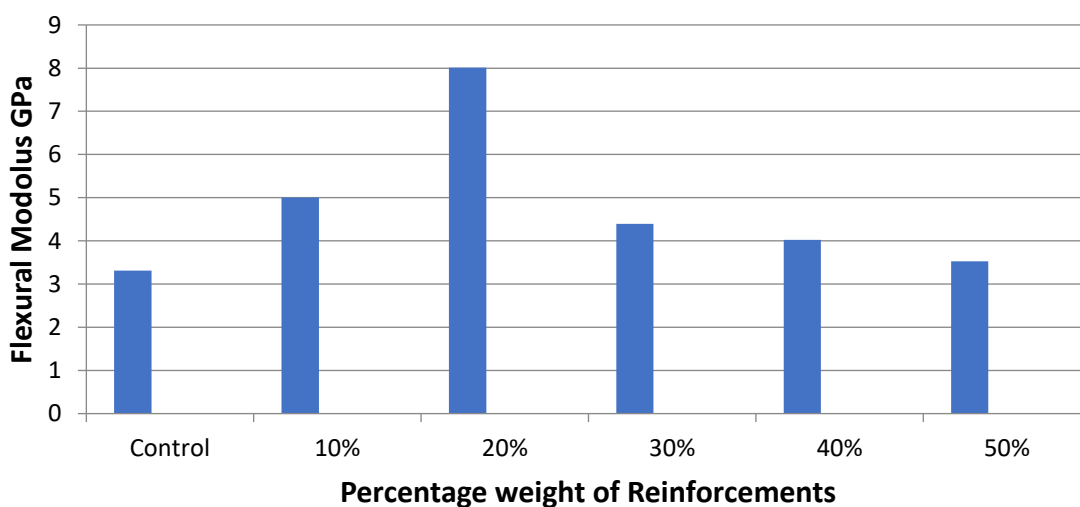


Figure 9: Effect of Reinforcement on Flexural Modulus of BPE Composites

3.6 Impact Strength

Figure 10 shows the result of the impact strength of Palmyra fiber and Balanite shell particles reinforced epoxy composites with their different percentage compositions. The combination at 30% reinforcement gave the maximum impact strength of 0.494 J/mm. The control sample, pure epoxy had impact strength of 0.183 J/mm. From this value, an improvement of 63% was achieved at 30% reinforcement before it dropped at higher material loading. This decrease is as a result of voids formed due to higher material loading that caused easy fiber pullout which affected the fiber-reinforcement bonding. Saba *et al.* (2019) also observed an improvement in impact strength when reinforcement was added, but there was a negative change in the impact strength when fiber was loaded continuously. Addition of reinforcement increased the brittleness of the composite and therefore a reduction in impact strength with continuous loading of reinforcement.

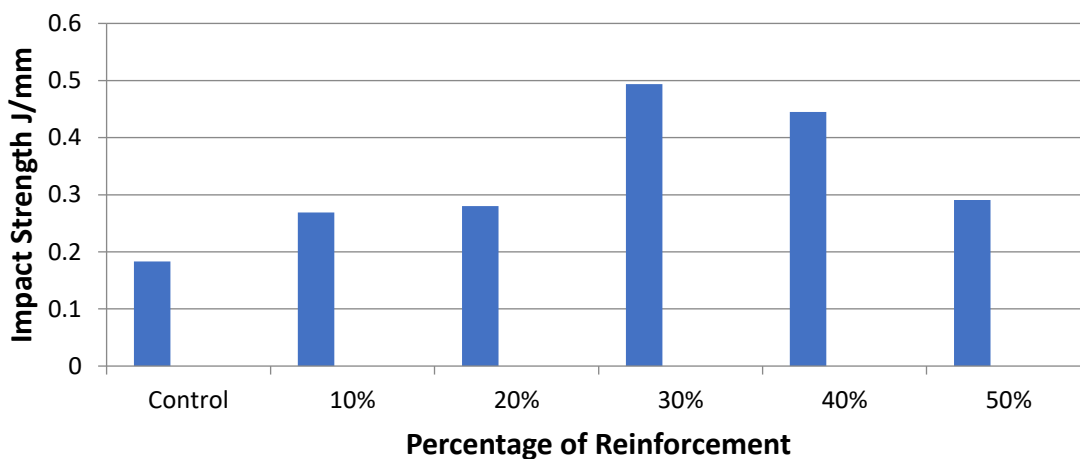


Figure 10: Effect of Reinforcement on the Impact Strength of BPE Composites

The SEM result in Plate 5 shows the dispersion of Balanite shell particles and Palmyra fiber due to the impact energy exerted on the composite with 30% reinforcement. Though the impact force had an effect on the reinforcement arrangement on the composite as observed at the topmost part of Figure 11, impact load was transferred to the Palmyra fiber and Balanite shell particles which made impact stress to be minimal. Unequal distribution of the matrix on the fiber increased the brittleness of the composite which resulted in its failure.

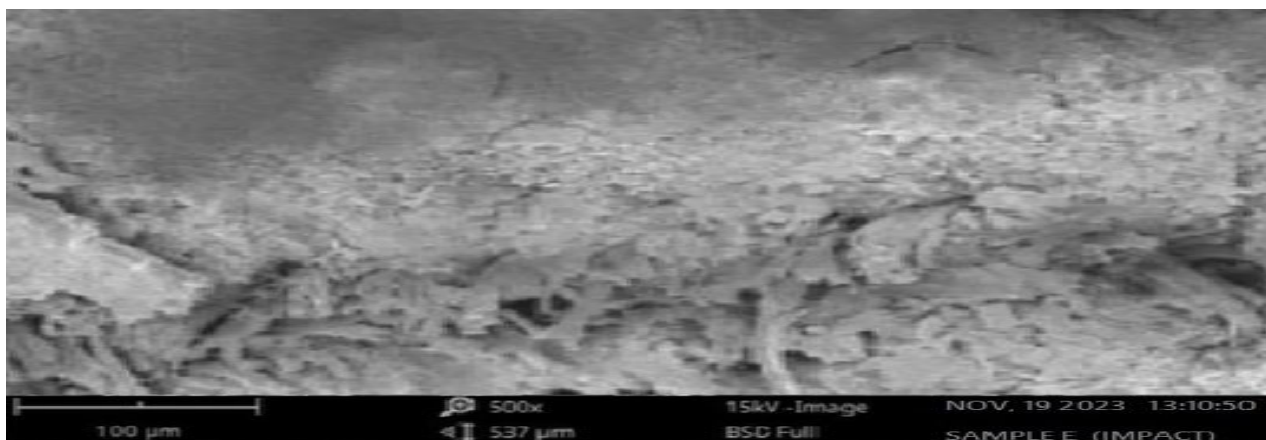


Figure 11: SEM Micrograph of 30% Reinforcement Impact Strength Sample

4. Conclusion

Balanite shell particles and Palmyra fiber reinforced epoxy hybrid composite was successfully produced using the hand lay-up method and compression molding operation. Characterization of the produced composite revealed that reinforcing pure epoxy with Balanite shell particles and Palmyra fiber improved its tensile, flexural and impact properties. Tensile strength reached its peak when 30% of reinforcement was added resulting to 44% improvement on the tensile property of the matrix while the highest value for flexural strength was obtained when 20% of reinforcement was added which is as a result of the brittle nature of the composite that became clearer with the three-point bending test. The highest flexural property obtained shows that the flexural property of pure epoxy was improved by 34%. Addition of 30% reinforcement increased the impact strength of the composite to its highest value which indicated 63% improvement on pure epoxy. This composite can be used in low to medium strength applications such as automobile interior parts and household equipment like Waldrop.

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