## Evaluation of some Properties of Polyester Based Hybrid Composites Produced From Luffa-Banana Fibres

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**Abstract**

This study presents the evaluation of the mechanical, physical and dynamic mechanical properties of luffa-banana fibre reinforced polyester hybrid composites. The luffa fibre and banana fibres were extracted from luffa plant and banana stem respectively by manual stripping into strands. The luffa and banana fibres were then blended in the ratio of 50:50 for the production of the hybrid composites using hand lay-up method. Polyester-resin was used as binder and the percentages of luffa-banana fibres used were 3, 5, 6, and 9 %. The tensile strength, impact strength, flexural strength, density, water absorption, and the dynamic mechanical analysis (DMA) (storage modulus, loss modulus damping factor) of the produced luffa-banana hybrid composites were evaluated. The results of the density and water absorption obtained varied from 0.84-1.23 g/cm$^3$ and 0 - 0.35 % respectively. The tensile and impact strengths (3.46 - 9.27 MPa and 0.66-3.26 J/cm$^2$) of the produced hybrid composites were observed to increase with increasing fibre content from 3 - 6 % and decreased at 9 %. The results of DMA revealed that loss modulus of the hybrid composites and pure polyester were found to increase with increasing temperature up to glass transition temperature and then decreased. The damping factor was observed to increase with increasing temperature and goes at maximum level in transition region and while decreasing the in rubbery region. The properties of the produced hybrid luffa-banana composites showed that luffa and banana fibres can be used in synergy as raw materials for composites manufacture. As the properties evaluated were in agreement with standard composites used as interior design of cars.

**Key words:** Mechanical properties, Dynamic mechanical analysis (DMA), Luffa fibre, Banana fibre, Polyester, Hybrid composites

## Introduction

Hybrid composites are one of the emerging fields in polymer science that are gaining attention for application in various sectors, such as building, aeronautic and automotive. The concept of hybridization provides flexibility to the design engineer to tailor the material properties according to particular requirements, as the behavior of the hybrid composites appears to be, in general, a weighted sum of the contributions of the individual components in which there is a balance between their advantages and disadvantages (Romomazini *et al*, 2013). Nitin and Singh (2013) stated that plant fibres played an important role in the composite industry and it can be classified according to their origin. According to Kiruthika (2017), the advantages of natural plant fibres/particulates over traditional fibres/particulates are acceptable as good specific strengths and modulus, economic viability, low density, reduced tool wear, enhanced energy recovery, and reduced dermal and respiratory irritation with good biodegradability. Ahmad, *et al*. (2015) also affirmed that the attractive features of natural fibres have been their low cost, light weight, high specific modulus and health hazards. These advantages have placed the natural fibre composites among the high performance composites having economic and environmental advantages. The application of natural cellulose fibres as reinforcements in composite materials have found increased use over the last few years (Azeez *et al*, 2013). Various natural fibres such as banana, sisal, jute, bargasse, coir and luffa are used as reinforcement materials (Pickering *et al*, 2016).

Numerous researchers have investigated the production of hybrid composites using natural/vegetable fibres as reinforcements. Among these are Aji *et al* (2012), Idicula *et al* (2010), Pothan *et al* (2010) and Venkatachalam *et al*. (2015). According to Venkatachalam *et al* (2015) and Dilara (2008), Luffa fiber is a light-weight material with high specific energy absorption capacity. Mani *et al* (2014) stated that Luffa fibres obtained from *Luffa-cylindrica* locally called "sponge-gourd" is one such natural resource whose potential as fiber reinforcement in polymer composite has not been explored till date for tribological applications. Banana fibre at present is a waste product of banana cultivation and banana is extensively available throughout the tropics. It is present in the outer portion which covers the central stem region of the tree (Kiruthika (2017). This study focuses on the evaluation of the physical, mechanical and dynamic mechanical properties of polyester reinforced Luffa–banana hybrid composites.

## Materials and Methods

### Preparation of the raw materials

The luffa fibres used in this work were obtained from a Luffa plant found in Efekwo/Ugbokolo in Benue State of Nigeria. The fibre strands were obtained by light pounding of the plant stem using mortar/pestle and subsequently soaked in water for 24 hours. The strands were further reduced into smaller strands and sun dried for 72 hr. The banana fibres used were obtained from the stem of banana and the fibre strands were obtained by slicing the stem severally. The fibres were soaked in water for 3 hours and then sun dried for 72 hours to remove free water present, dirt and other agents in the fibre. The dried fibres were cut into lengths of 20 mm each. The fibres are shown in Figure 1.

(a)Luffa (b) Banana

**Fig. 1:** Luffa and Banana Fibres

**Sample preparation**.

The luffa and banana fibres were blended in the ratio of 50:50 for the production of the composites. The compositions 3, 5, 6, and 9 % luffa-banana fibres were separately added to unsaturated polyester resin in 1.2 g of accelerator and properly mixed to form a gel. The mixtures were adequately stirred and poured into the mould. The fibres were arranged parallel to one another in order to avoid entanglement the casts were allowed to set before being stripped from the mould after compressing using a load of 10 kN. Figure 2 shows one of the samples produced.

**Fig. 2:** One of the samples produced

**Evaluation of the properties composites**

**Physical properties**

**Water Absorption Test:** The samples were cut into same size of 4 cm by 4 cm and weighed using a digital electronic weighing scale Model GOLDEN – METTLER prior to immersion into beakers containing water at room temperature. The samples were immersed in water, taken out periodically, water wiped out from the surface of the samples and weighed immediately and reweighed to find out the content of water absorbed. The specimens were weighed regularly at intervals of 24 hours, for a period of 480 hours that is 19 days. The water absorption was calculated by the weight difference using the expression in equation (1) (Nitin and Singh 2013).

$$\text{Water absorption (\%)} = \frac{W2 - W1}{W1} \times 100 \qquad 1$$

Where $W_2$ is the final weight after 24 hours of immersion, $W_1$ is the initial weight before immersion

**Density Test:** The density of the composite was carried out using Archimedes principle and each pre-weighed sample size of 4 cm by 4cm was immersed in a beaker containing a known level of water and the difference between the initial and final level of water in the beaker was calculated as the volume of the sample. The densities of the samples were evaluated using equation (2) (Tewari *et al*, 2012)

$$\rho = \frac{M}{V} \quad (g/cm^3) \qquad (2)$$

Where $\rho$ is the density of the sample, M represents the mass of each sample and V is the volume of the sample.

**Mechanical properties**

**Tensile test:** The tensile strength of the produced composites were measured with a Monsanto Tensometer Type W with S/No. 9875 in accordance with the ASTM D638 procedure. The dimensions of the sample was 100 mm x 10 mm x 5 mm with gauge length of 40 mm. The test was conducted by gripping each end of a reduced section specimen and slowly pulling it until catastrophic failure occurs.

**Flexural test:** The flexural test was performed using a Universal materials Testing Machine 100 kN Capacity, model no. Cat. Nr. 261 in accordance with ASTM D790 using the 3- point bending fixture that uses centre loading on a simple supported beam. The specimens of dimension 100 mm x 30 mm x 5 mm were rested on two supports and loaded by means of a loading nose midway between the supports.

**Impact test:** The impact strength test of the sample was done using the Charpy impact testing machine with capacities of 15 J and 25 J, and model no. Cat. Nr. 412 and in according with ASTM standard D- 256. In this method, the specimen was supported horizontally as a simple beam and fractured by a blow delivered in the middle by the pendulum. The sample size was 80 mm x 10 mm x 5 mm.

**Dynamic mechanical analysis (DMA)**

The dynamic mechanical analysis (DMA) was conducted using a Dynamic Mechanical Analyser Model no. 242E on two samples (3 and 5 %) with the best physical and mechanical properties using sample dimension of 60 mm ×12 mm × 5 mm. The samples were separately introduced into the combustion chamber of the equipment and subjected to sinusoidal stress using a temperature sweep of 30 – 180 °C, at frequency loading of 2, 5, and 10 Hz with dynamic amplitude of 60 μm. Having scanned through a range of temperatures, the glass transition and other material relaxation characteristics associated with the samples were identified by a decrease in its storage modulus, a peak in its loss modulus and loss factor.

**Results and Discussion**

**Physical properties**

**Water absorption:** The water absorption of the produced hybrid composites as shown in Figure 3 was observed to increase with increasing fibre contents. The amount of water absorbed by the produced composites varied from 0 - 35 % and the water absorption into all the samples were observed to remain constant at the 9th day of immersion. It is interesting to note that beyond 19 hours of immersion there no water absorption in all the samples produced. This implies that the composites can be used in areas where water is present without deteriorating.

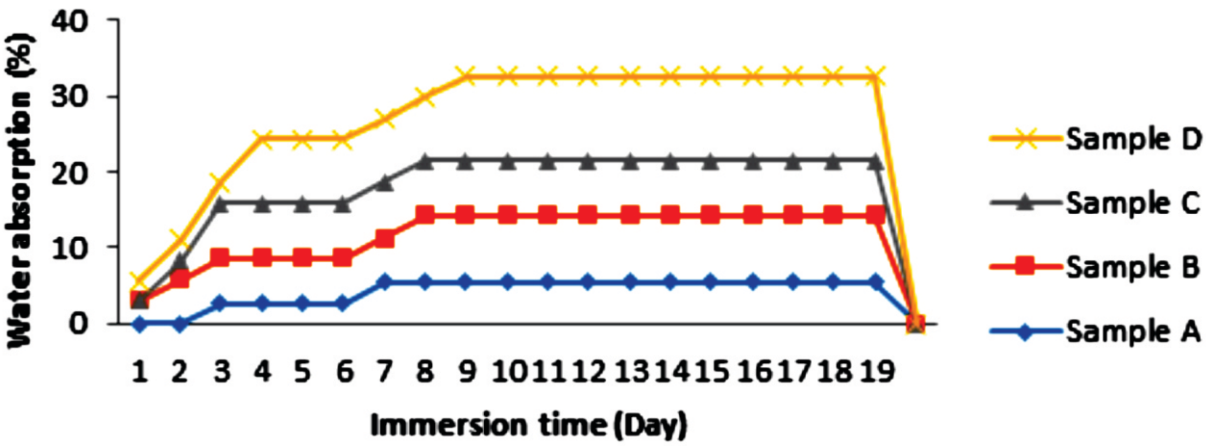


**Fig. 3:** Variation of water absorption against Immersion Times for the produced samples

**Density:** The density of the produced hybrid composites as shown in Figure 4 was observed to decrease with increasing banana-luffa fibre contents. The density ranged from 0.84 – 1.23 g/cm$^3$ as it can be further seen that there was a slow drop in density between 3-9 % respectively. The reason for the drop in density could be the reason given by Nitin and Singh (2013) that the presence of porosity/voids would be there which decreases the density because there could have been enough pressure applied during compression. The values of density obtained from the produced hybrid composites were similar to the values of 1.23, 1.25 and 1.29 g/cm$^3$ obtained from glass-ramie hybrid composites as reported by Rommanzi *et al* (2015). The density values were also in agreement with the values of 1.04 (15 %), 0.99 (20 %) and 0.80(30 %) g/cm$^3$ obtained by Tewari *et al* (2012) for composites produced from bagasse – glass fibre reinforced composites. The implication of this result is that careful production of luffa-banana hybrid composites may have varieties of industrial application when weight and strength is to be the critical parameter in the design.

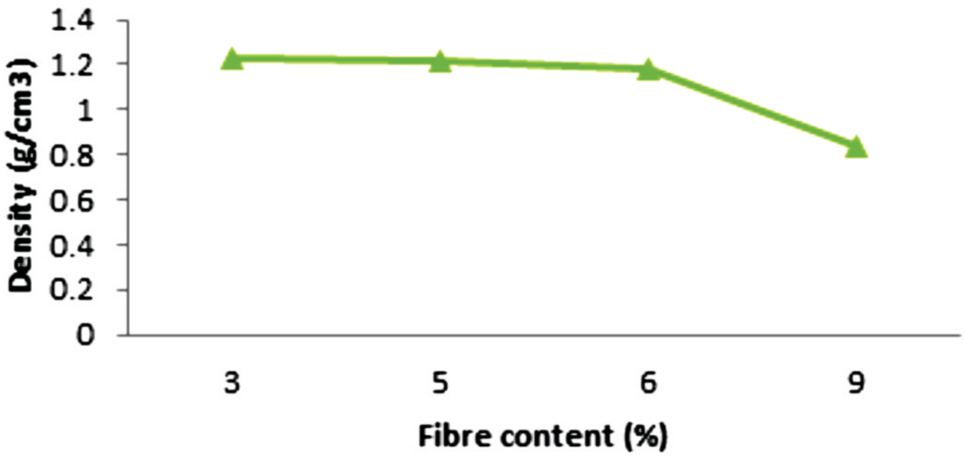


**Fig. 4:** Density of the produced hybrid composites from luffa-banana

**Mechanical properties**

**Tensile strength:** The tensile strength of the produced hybrid composites as shown in Figure 5 varied from 3.46 – 9.27 MPa. The tensile strength was observed to increase with the addition of luffa-banana fibre contents (3 – 9%) in the matrix which clearly showed that the application of fibres created a reinforcing effect that was responsible for the increase in tensile strength. However, at some point of further increase in the fibre content at 9 %, a decrease in the tensile strength was observed. This trend was confirmed by Das and

Biswas (2016) who stated that; the improper adhesion of the fibres to the matrix hindered the increase of tensile strength. Pickering *et al*. (2016) stated that fibre wettability has been shown to affect tensile strength of composites, and that good fibre dispersion promotes good interfacial bonding thereby reducing voids by ensuring that fibres are fully surrounded by the matrix. The highest tensile strength was observed at around 3 % fibre loading and could be explained by better fibre distribution in matrix material. The values of tensile strength obtained from luffa-banana hybrid composites were in agreement with 9.5 MPa from luffa fibre composite at 30 % and better than 6.6 MPa at 10 % as reported by Mani *et al* (2014). The values were also similar to the value of 9.6 MPa luffa and groundnut reinforced epoxy polymer hybrid composites reported by Panneerdhass *et al* (2014).

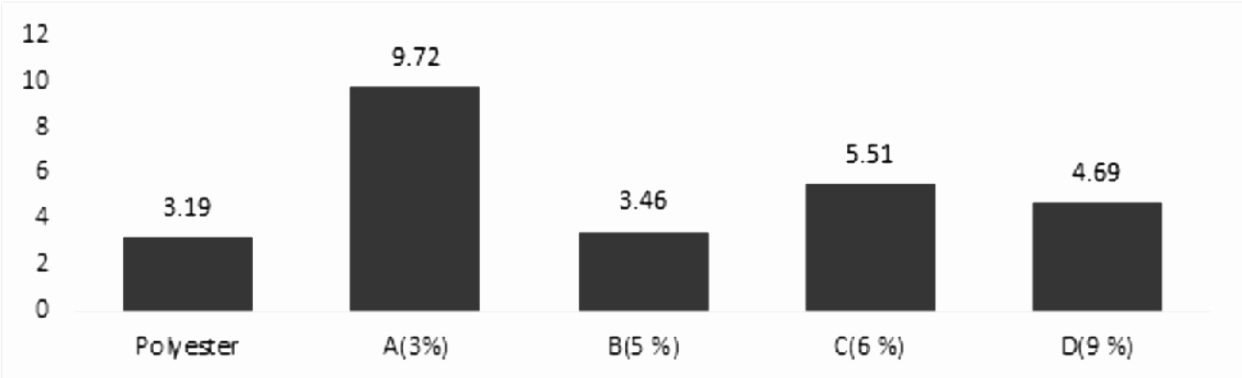


**Fig. 5:** A bar chart showing Tensile Strength of hybrid composites produced from Luffa-Banana Fibres

**Impact strength:** Figure 6 presents the impact strength of the produced hybrid composites which is the capability of the material to withstand a suddenly applied load normally expressed in terms of energy. The impact strength was observed to increase with increasing fibre contents and varied from 0.66 – 3.26 J/cm$^2$. However, there was a decrease in impact strength (0,88MPa) at fibre content of 9 %. This may be attributed to the weak interfacial interaction between the fibre and matrix material for higher fibre content that was beyond 6 %. Similar behaviour of the composite specimen was also observed by Mani *et al* (2014) and this the authors attributed to the fact that the reinforcing particles been cellulose, absorbed more potential energy as its content increased in the matrix material. The values of impact strength obtained by the produced hybrid composites were better than the values of 0.002205, 0.002205 and 0.002701 J/cm$^2$ for 10 % bagasse based composite, 20 % for bagasse-glass fibre composites and 30 % for bagasse-glass fibre respectively as reported by Tewari *et al* (2012).

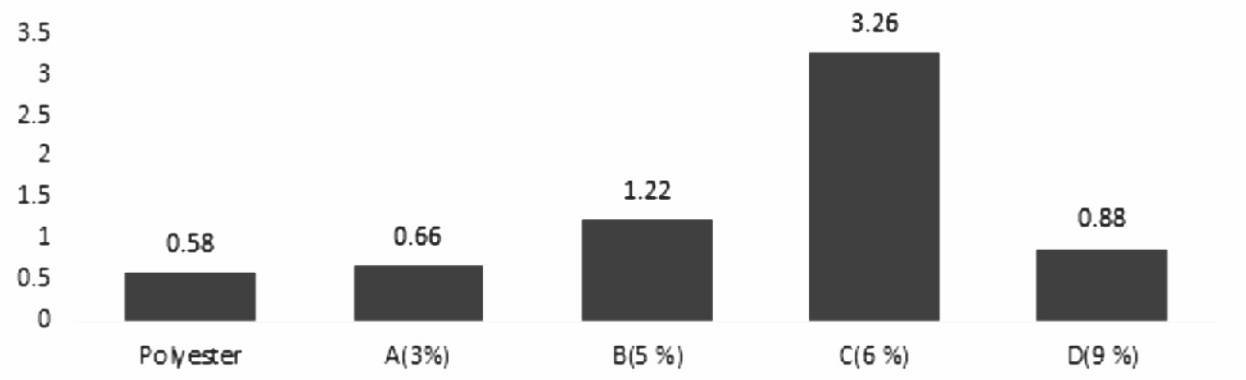


**Fig. 6:** A bar chart showing the Impact strength of luffa- banana hybrid composite

**Dynamic Mechanical Analysis Results**

Dynamic mechanical analysis (DMA) is an effective tool used in studying the thermostable properties of materials as it allows the materials respond to temperature, stress, frequency and other conditions (Ekhlas 2016). DMA results are commonly presented in the form of a storage modulus (*E'*), a loss modulus (*E*") and damping

factor $\tan d = \frac{E''}{E'}$

**Storage Modulus:** The storage modulus at different frequencies (2, 5, and 10 Hz) for the hybrid composite produced and pure polyester as presented in Figures 7, 8 and 9 describe the ability of the produced hybrid composites to support a load. There was an evident enhancement in storage modulus with the addition of fibres in the matrix as compared to pure polyester. Obviously storage modulus (E') was observed to decrease with increasing temperature for the two samples (3 and 5 %) investigated and the polyester. The decrease in storage modulus values may be due to loss in stiffness of the fibre. This trend was in consonance with the findings of other researchers such as Ekhlas (2016), and Gupta and Srivastava (2015). It was also observed that the values of storage modulus increased with increasing frequencies and this affirmed the position of Ekhlas (2016) who stated that the dynamic elastic characteristics are material-specific, and their magnitude depends critically on the frequency as well as the measuring conditions and history of the specimen.

The values of storage modulus obtained peaked at 1750, 1700 and 1680 MPa for 5 % hybrid composite at frequencies of 10, 5 and 2 Hz respectively, while storage values of 1150, 1147 MPa and 1050 were obtained for 3 % hybrid composites. These peaked values of storage modulus obtained were better than the values of 1020, 1018 and 1000 MPa given by the polyester resin used. This clearly shows that the addition of luffa-banana fibres has improved the mechanical dynamic property of the polyester resin used.

**Loss Modulus:** Loss modulus is the amount of energy dissipated in form of heat by a material during one cycle of sinusoidal load. The values of loss modulus presented in Figures 10-12 for the produced composites and the polyester were observed to increase with luffa-banana fibre content over a temperature up to glass transition temperature and then suddenly decreased from the peak values. This trend could be due to free movement of polymer chains as all the loss modulus curves reached various maximum points (for maximum dissipation of mechanical energy) and decreased with higher temperatures (Romomazini *et al*, 2013). The maximum loss modulus value 170.5 MPa was obtained from 5% hybrid luffa-banana composite at frequency of 10.0 Hz. The maximum value of loss modulus exhibited by 5 % hybrid luffa-banana composite could be due to the reason given by Pickering *et al*. (2016) that higher degree of reinforcement tend to exhibit higher loss modulus and glass transition temperature ($T_g$).

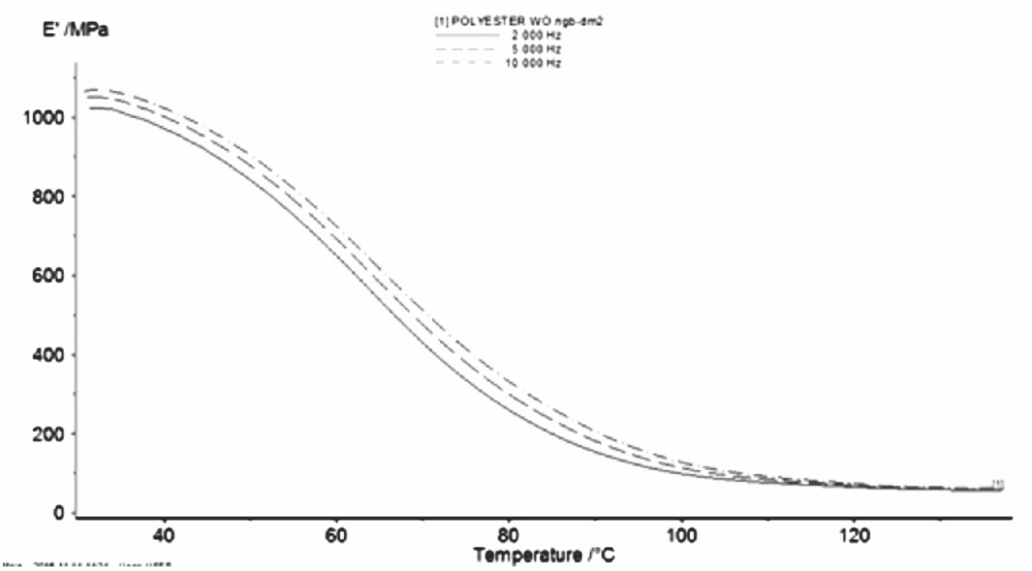


**Fig. 7:** Storage Modulus of 3 % Banana-Luffa Fibres

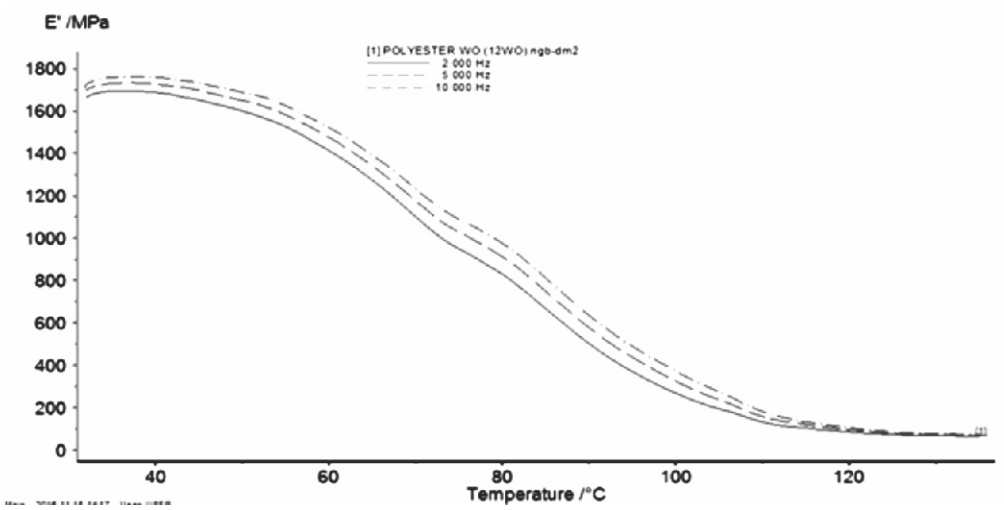


**Fig. 8:** Storage Modulus 5 % Banana-Luffa Fibres

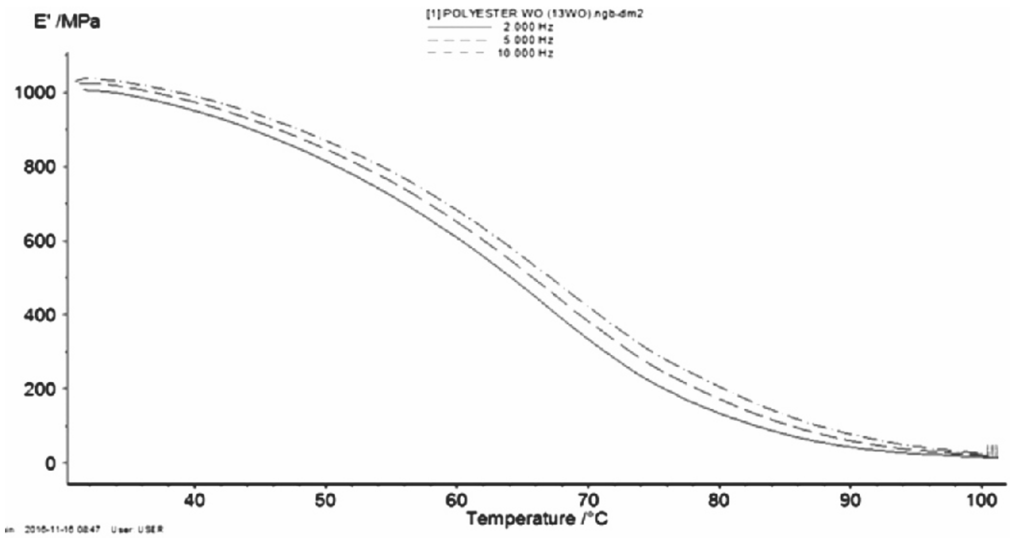


**Fig. 9:** Storage Modulus of 100 % Polyester Resin.

The glass transition temperature ($T_g$) which is the peak of either loss modulus or damping curve was observed to vary from 67-65$^{o}$C, 69.2-78$^{o}$C, and 81-86 $^{o}$C for polyester, 3 and 5 % luffa-banana composites respectively. The values of the glass transition temperature from the produced composites were observed to shift to higher temperature due to the incorporation of luffa-banana fibre into the composite leading to decrease in mobility of the polyester as reported by Ekhlas (2016)

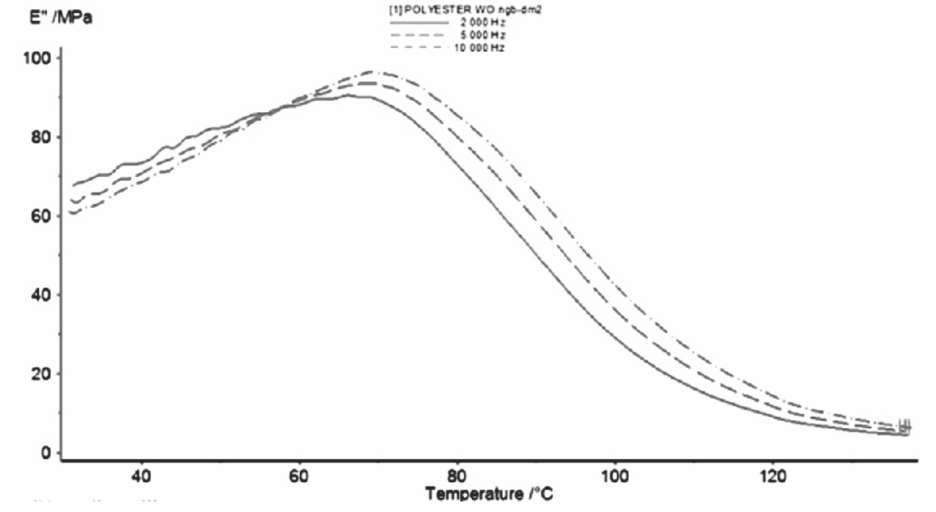


**Fig. 10:** Loss Modulus of 3 % Banana-Luffa Fibres

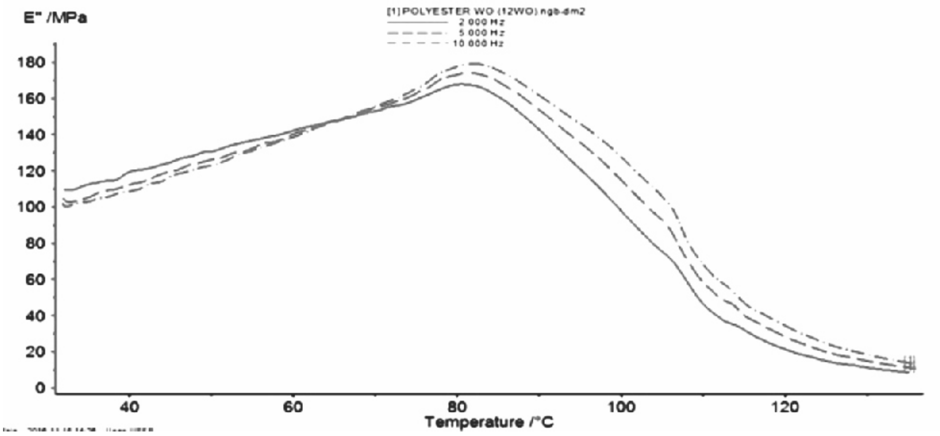


**Fig.11:** Loss Modulus of 5 % Banana-Luffa Fibres

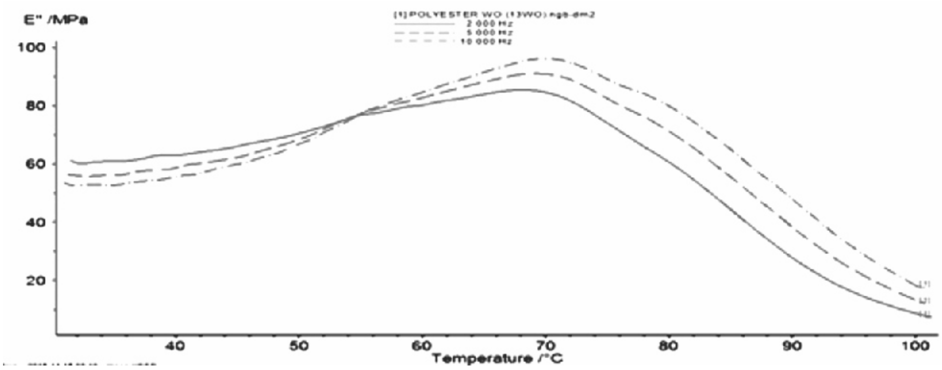


**Fig. 12:** Loss Modulus of 100 % Polyester Resin

**Damping factor:** The damping curves for the two luffa-banana hybrid composites and the polyester are shown in Figures 13, 14 and 15 respectively. Damping is the dissipation of energy in a material under cyclic load and it is a measure of how well a material can get rid of energy which is normally reported as the tangent of the phase angle. It reveals how good a material will be at absorbing energy. The display of the Figures 13 and 14 revealed that with the incorporation of luffa-banana fibres, damping factor increased with increase in temperature and goes at maximum level in the transition region while decrease in the rubbery region. The damping peaks in a composite indicate that once the deformation is induced in a material, the material will not recover its original shape (Pothan *et al*, 2010). The damping values for the produced 3 and 5% luffa-banana hybrid composites and polyester varied from 0.34 –0.31; 0.37 – 0.35; and 0.66 – 0.60 respectively

The lower values of damping factor obtained by the produced hybrid composite show that the samples exhibited good load capacity and strong adhesion between fibres and matrix as reported by Pothan *et al*, (2010). The values of damping factor (0.60 – 0.66) for the pure polyester were higher than the value obtained from the produced hybrid composite composites. This could be that there was no restriction to the chain motion in the case of pure polyester resin, while the presence of the cellulose fibres hindered the chain mobility, resulting in the reduction of sharpness and height of the damping factor as reported by (Ekhlas 2016). The glass transition temperatures ($T_g$) obtained from Figures 11-13 varied from 86 – 98 $^0$C, 106– 110 $^0$C, and 91 – 98 $^0$C for luffa-hybrid composites 3 %, 5 % and pure polyester at various frequencies of 2.00, 5.00 and 10.00 Hz respectively.

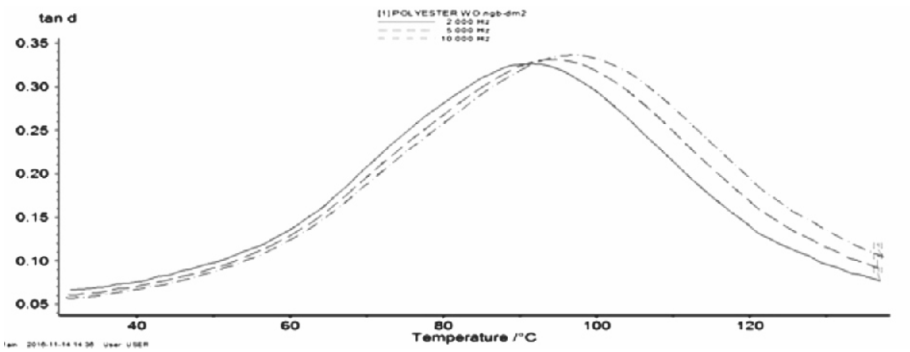


**Fig. 13:** Temperature against damping factor of 3 % Banana-Luffa Fibres

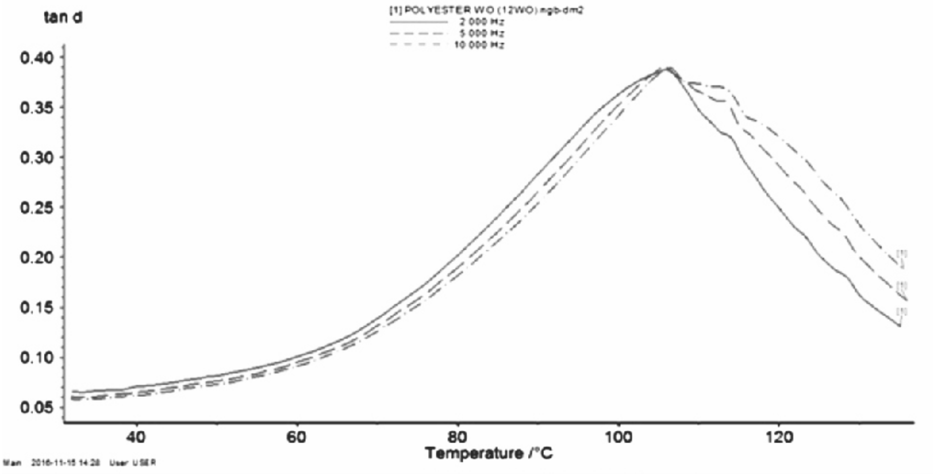


**Fig. 14:** Temperature against damping factor of 5 % Banana-Luffa Fibres

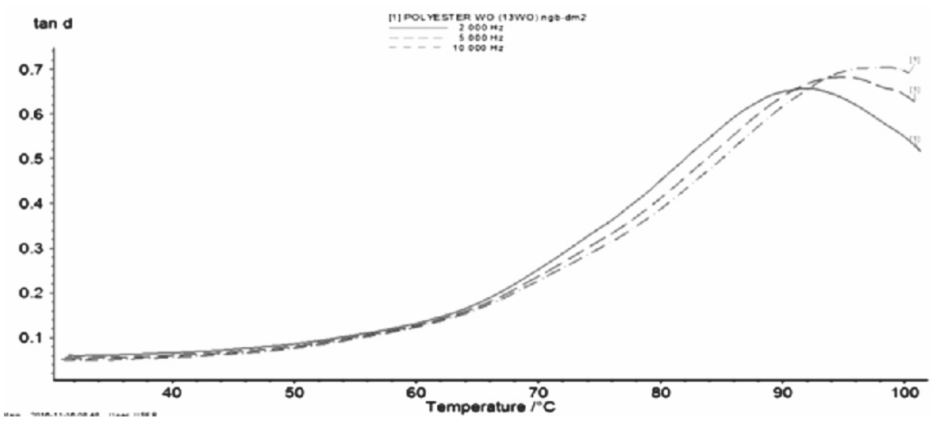


**Fig. 15:** Damping factor of 100 % Polyester Resin

## Conclusion

The aim of hybridization of luffa and banana fibres was to improve the physical, mechanical and dynamic properties of the composites produced. It can be concluded that the values of the mechanical properties of luffa-banana reinforced hybrid composite were a little bit better than that of the luffa fibre reinforced composite. These mechanical properties were in agreement with other composites produced from some natural fibre reported in literature. Density of the hybrid luffa-banana fibre composites decreased with increasing fibre content as compared to pure polyester. Dynamic properties of the hybrid luffa-banana polyester composites were found to depend on volume fraction of the fibre. The storage modulus and loss modulus were found to be higher for hybrid composite than pure polyester. It can be concluded that hybrid composites produced from luffa-banana fibres can be utilized as a material for cars interior designs.

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