Scientific Research Journal,
Vol 18, No 1 (2021) 197 - 208
https://doi.org/10.24191/srj.v18i1.11385

SCIENTIFIC RESEARCH JOURNAL
SRJ
ISSN: 1675-7009
e-ISSN: 2289-649X

Effect of Fibre Weight Fraction on the Flexural and Dynamic Mechanical Properties of *Arenga Pinnata* Fibre and Its Hybrid Composites

Abdul Hakim Abdullah*, Amerul Farhan Amri, Farrahshaida Mohd Salleh, Nurul Hayati Abdul Halim and Izdihar Tharazi

Faculty of Mechanical Engineering, Universiti Teknologi MARA 40450 Shah Alam, Selangor, Malaysia

**Corresponding author's e-mail: hakimnen@uitm.edu.my*

Received: 3 December 2020
Accepted: 11 January 2021
Online first: 1 April 2021

ABSTRACT

This study aims to investigate the influence of fibre weight fraction on the flexural and dynamic mechanical properties of Arenga pinnata fibre and its hybrid epoxy composites. In this work, four composites configurations were fabricated using hand lay-out by varying fibre weight ratios between Arenga pinnata (AP) and glass fibre (GF); AP100% - 0%GF, AP70% - 30%GF, AP30% - 70%GF and AP0% - 100%GF, respectively. The flexural modulus indicates that the pure Arenga pinnata composites (AP100%-0%GF) are stronger than both hybrid and pure glass fibre composites (AP0%-100%GF). The increasing fibre weight fraction of glass fibre has resulted in lower flexural properties. By dynamic mechanical analysis (DMA), the storage modulus of pure Arenga pinnata composites is always higher and have better thermal resistance as compared to the pure glass fibre composites. The result indicates that Arenga pinatta fibre reinforced with epoxy composites have a great opportunity similar to that glass fibres composites counterpart in engineering application.

***Keywords**: hybrid composites, kenaf, glass, fibre weight fraction*

PENERBIT PRESS
UNIVERSITI TEKNOLOGI MARA

INTRODUCTION

Nowadays, growing environmental awareness has resulted in a renewed interest in using natural material for many applications. This situation encourages many industrial players such as automotive, packaging and construction to search for new biodegradable materials. The disadvantages of human-made composites materials such as glass, carbon and aramid are that they are not biodegradable, expensive, abrasive and, making them difficult to recycle or dispose of at the end of their life [1]. As a result, natural fibre composites have become realistic alternatives to replace the glass-reinforced composite in many applications.

Natural fibres such as hemp, flax, jute, pine, kenaf and sisal and *Arenga pinnata* (AP) are generally lower in cost and density. Other advantages of using natural fibres are that they are renewable material sources, lower greenhouse gas emission, enhanced energy recovery, and at the same time, natural fibres could provide sufficient mechanical strength as compared to human-made fibres.

The properties of mechanical properties can be tailored through hybrid composites, for which different fibres are combined in the same matrix to give advantages over one type of fibres with the lacking of properties in the other fibres [2]. Several studies reported that natural fibre/glass fibre hybrid composites mechanical and thermal properties have improved [3], [4]. It is reported that the incorporated *Arenga pinnata* with glass fibres hybrid composites has resulted in 50% less weight in a boat because the density of sugar palm fibre is lower, 1.22–1.26 g/cm³, as compared to commercial E-glass fibre (2.55 g/cm³) [5].

Mechanical properties of a composite are dictated by the amount of fibres embedded in a matrix, in term of fibre volume fraction, V_f or fibre weight fraction, W_f. Both V_f and W_f is interchangeability by the following:

$$V_f = \frac{W_f/q_f}{W_f/q_f + (1 - W_f)/q_N} \tag{1}$$

$$W_f = \frac{q_f V_f}{q_f V_f + q_N (1 - V_f)} \tag{2}$$

Where *pf* and *pm* is the density of fibre and density of matrix, respectively, it is reported that the increasing fibre weight fraction and fibre volume fraction improves the mechanical properties of natural fibres composites [6], [7]. However, fibre weight fraction uses are not commonly reported in natural fibre/glass hybrid composites, probably due to the significant difference in fibre density between glass fibre and natural fibre.

In this research work, *Arenga pinnata* fibre and glass fibre reinforced epoxy composites were studied using fibre weight fraction. The hybridised version of composites was also evaluated by varying *Arenga pinnata* fibres and glass fibre weight ratio. The study began with the determination of flexural properties and followed by the dynamic mechanical analysis (DMA). The study is significant because it explores the potential of the abundant resources of *Arenga pinnata* from the forest for uses as fibre in reinforced composite

EXPERIMENTAL PROCEDURE

Materials

The raw *Arenga pinnata* fibre was harvested manually form its plant in a small village in Nilai, Negeri Sembilan, Malaysia. The retting process was applied to separate the stalk from the core of the fibre. In this process, bundles of *Arenga pinnata* fibre were soaked in a water tank until the dirt vanished from the core section, and the stalk was separated from the core. The fibre stalks were occasionally stirred to facilitate the separation process. The water was changed several times to reduce the dirt resulting from the retting process. The fibre was dried for about two weeks at room temperature before composites fabrication.

Glass fibres (E-glass) in the form of roving configuration was supplied by the Composite Lab of Faculty of Engineering University Technology Mara (UiTM) Shah Alam. Epoxy resin was used as the matrix for composite fabrication. Two-component epoxy and hardener (BBT-7891/7892) were purchased from Berjaya Bintang Timur Sdn Bhd at Cheras, Selangor, Malaysia.

Composites Fabrication

Composites were fabricated using the hand lay-out technique. To attain a similar fibre weight fraction, each fibre was weight similarly using a precision weight balance. 21 g of fibres were used for making a composite pate. A composite plate sizing corresponds to the mould size (250 mm in length, 150 mm in wide and 4 mm in thickness). The samples configuration and their respective fibre weight content are shown in Table 1.

The composites fabrication began with the long random fibre and/or woven roving fibre placed and aligned inside the mould. Epoxy and hardener were then mixed in a plastic cup based on the weight percentage 5:1 (epoxy: hardener). The mixture was slowly stirred with a plastic spoon constantly for about eight to ten minutes to make sure the mixture was mixed completely. Then the matrix was poured over the fibre and compressed and distribute evenly until it achieved a thickness of 4.0 mm. Then, a transparent hard plastic was placed above the composite plate, pressed, and pushed down with the finger to avoid and eliminate the bubbles. An aluminium plate and weight were placed on the mould to remove the excessive epoxy and to ensure the flat surface of the composite. Samples were left for 1st day for curing at room temperature condition (25-30°C). Finally, the cured composites (Figure 1) were removed from the mould and cut for the desired test.

Table 1: Composites Configuration and Fibre Weight Used in Making the Composite Plate

Composites	Weight of Fibre Used (g)	
	Arenga Pinnata Fibres	Glass Fibres
AP100%-0%GF	0	21.0
AP70%-30%GF	14.7	6.3
AP30%-70%GF	6.3	14.7
AP0%-100%GF	21.0	0

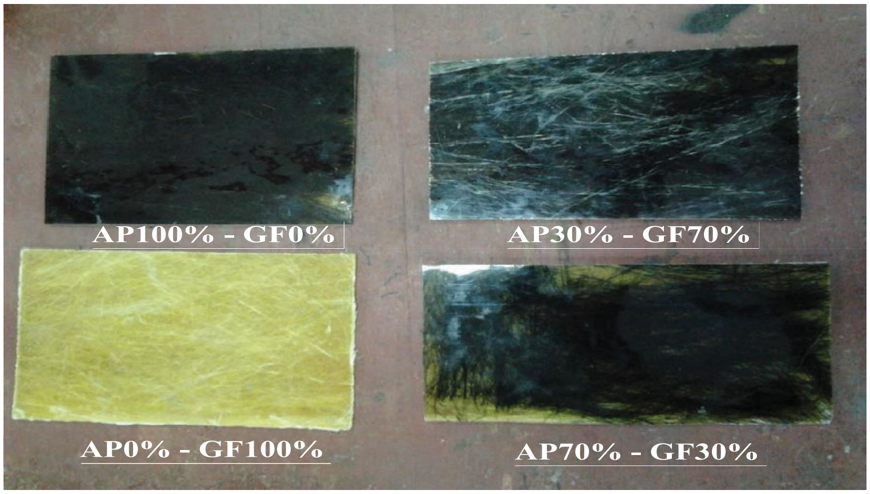

Figure 1: Cured Samples After Composites Fabrication

Flexural Test

The flexural test was performed using the Instron Universal Testing Machine on the 3-point bending configuration according to ASTM D790 standard with 100 mm of the support span. Samples was a rectangular shape having 13 mm in wide, 4 mm in thickness and 270 mm in length. The specimens were loaded at a crosshead speed of 2 mm/min up to failure. At least five samples were tested for every configuration. The flexural modulus was calculated from 0.25-0.5% of flexural strain.

DYNAMIC MECHANICAL ANALYSIS (DMA)

DMA test was done using DMA 8000 machine at Nano Science-Tech UiTM Shah Alam. The DMA measured the storage modulus, loss modulus and tan 6 (damping). The DMA evaluation was performed from 27 °C till 90 °C with a ramp rate at 5 °C/min. Samples having 27 mm long, 4 mm thickness and 10 mm wide was loaded on a dual cantilever configuration inside the heating chamber.

RESULT AND DISCUSSION

Flexural Test

The effect of fibre weight fraction was investigated by flexural test. Flexural strength and flexural modulus of pure *Arenga pinnata* (AP100% - 0%GF), glass fibre (AP0% -100%GF) and their hybrids composites (AP70% - 30%GF and AP30%-70%GF) are presented in Figure 2. It is interestingly to observe that pure *Arenga pinnata* composites have a higher flexural modulus, which is 6770.6 MPa, followed by the hybrids (6422.2 – 6069.1 MPa) and glass fibre composites (558.0 MPa). In the case of flexural strength, there is a slight reduction of flexural strength of *Arenga pinnata* composites, but the result is still higher than the glass fibre composites. The flexural strength of AP70% - GF 30% is the highest at 84.9 MPa. The result of flexural properties is obviously is not in agreement with research reported by Flynn, Amiri, and Ulven (8), which shows the flexural modulus of flax/carbon hybrid composites decreased with increasing flax fibre volume fraction due to the presence of stronger carbon fibre in the composites. In the present investigation, it is expected that the fibre volume fraction of *Arenga pinnata* composites is higher than the glass fibre composites, and hence, ***Arenga pinnata*** composites have better flexural properties.

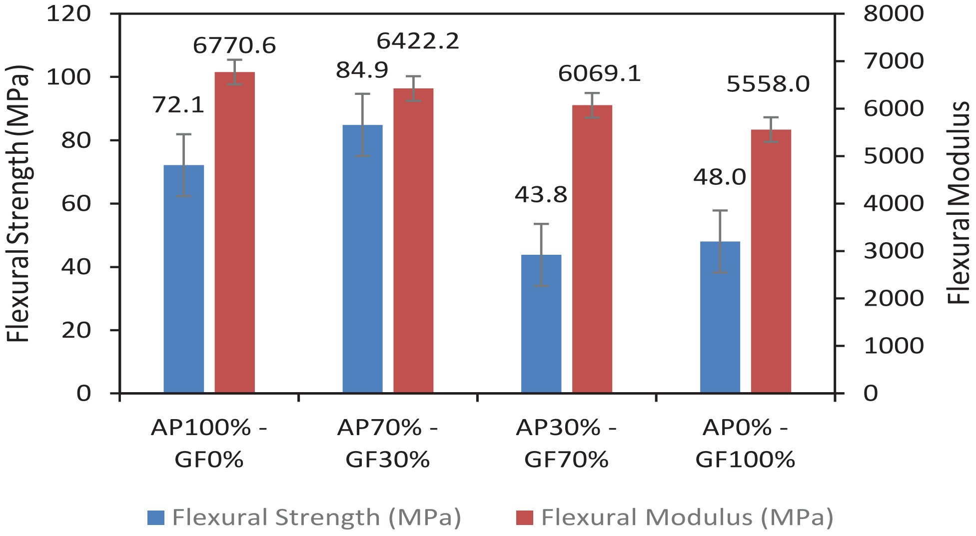

Figure 2: Flexural Properties of *Arenga pinnata* and Its Hybrid Composites

However, from another engineering perspective, the same weight of *Arenga pinnata* fibre could offer better flexural properties than the same weight of glass fibres in a composite. To quantify this, specific strength and specific modulus based on the fibre weight fraction between *Arenga pinnata* and glass fibre composites are calculated by dividing with their respective fibre density, as shown in Figure 3. It is interesting to observe that the specific strength of *Arenga pinnata* fibres composites is almost three times higher than glass fibre composites, 57.2 MPa/gcm-^{3} and 18.8 MPa/gcm-^{3}, respectively. *Arenga pinnata* fibres composites' specific modulus also increased up to 5248.5 MPa/gcm-^{3} compared to the glass fibre composites (2179.5 MPa/gcm-^{3}). Overall, the flexural result indicates that *Arenga pinnata* composites are stronger than glass fibre composites, and it is interestingly observed the hybrid version of composites between *Arenga pinnata* and glass fibre may not be necessary to improve the flexural strength and modulus if the uses of fibre weight fraction are being considered.

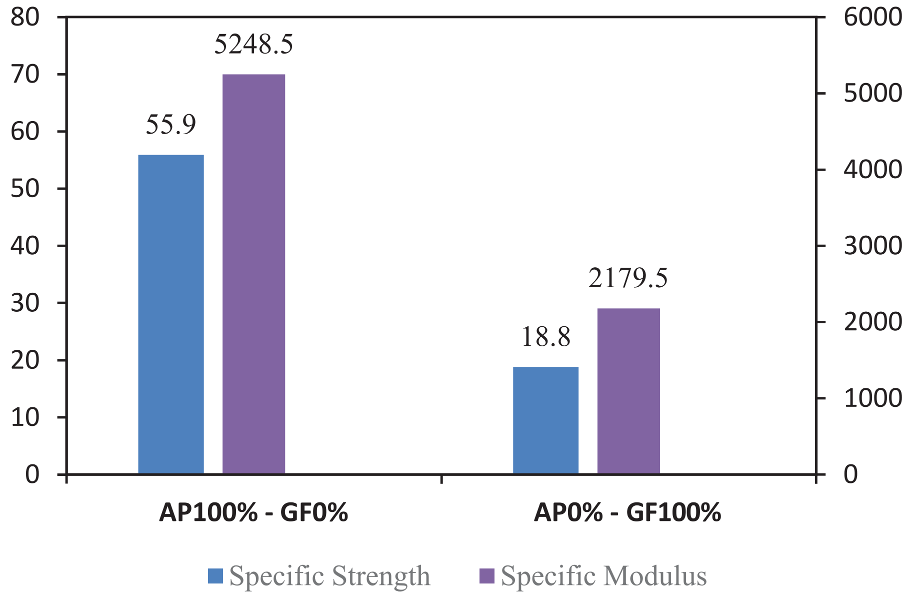

Figure 3: Specific Strength and Modulus Based on the Fibre Weight Fraction of *Arenga pinnata* and Glass Fibre Composites in Term of Fibre Weight Fraction

Dynamic Mechanical Analysis Storage Modulus

The variation in storage modulus with temperature can be seen in Figure 4. The storage modulus as the in-phase component is closely related to the load-bearing capacity of a material and is analogous to the flexural modulus. From the graph, it is observed that the storage modulus is consistent at low temperature before there was a rapid fall at a higher temperature. It interestingly to see that pure glass fibre composites, AP0% - GF 100%, had a rapid fall of storage modulus earlier (around 35 °C) as compared to hybrid composites (AP30% - GF 70% and AP70% - GF 30%) and pure *Arenga pinnata* composites (AP 100% - GF0%) which is occurred later at about 60°C. The result suggests that with the same amount of fibre weight fraction, *Arenga pinnata* and their hybrids composites have better storage modulus and thermal resistance than glass fibre composites counterpart. The result was, in fact, consistent with the trend of flexural modulus in Figure. In the case of varying fibre weight fraction between *Arenga pinnata* and glass fibres, it can be seen that the storage modulus of AP70%-GF30% was slightly improved as compared to the AF30%-GF70%, but the effect can be considered minimal.

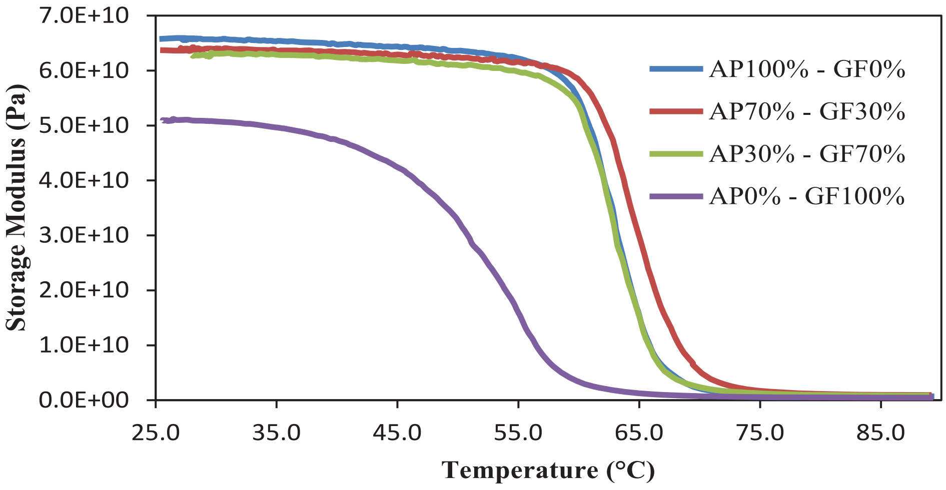

Figure 4: Variation of Storage Modulus, E', with the Temperature of *Arenga pinnata* and Its Hybrid Composites

Loss Modulus

The loss modulus is a measurement of energy loss (energy dissipation) from the materials. The variation of loss modulus with the temperature of *Arenga pinnata*-glass fibre hybrid composite at different fibre loading at a fix fibre weight fraction is shown in Figure 5. It is observed that the hybrid composites (AP30% - GF 70% and AP70% - GF 30%) have relatively lower loss modulus peak height than the non-hybrid composites, for which it is unexpected. However, there is an apparent shift loss modulus peak height for the pure *Arenga pinnata* composites, for which it has a higher loss modulus than the pure glass composites. This is expected because *Arenga pinnata* composites consisted of more fibre volume fraction, although they have the same fibre weight content. Therefore, the more embedded fibre in a composite is likely to increase the internal friction and promoting energy dissipation at the fibre/matrix interface [9].

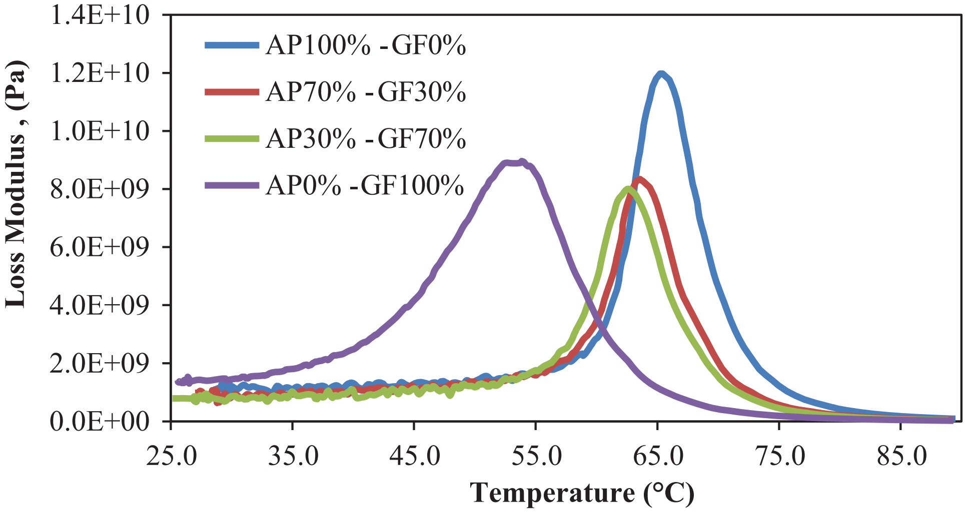

Figure 5: Variation of Loss Modulus with the Temperature of *Arenga pinnata* and Its Hybrid Composites

Tan ð (Damping)

DMA is an effective method to evaluate the fibre/matrix interfacial bonding in composites. The higher the tan 6 peak height, the poor the fibre/matrix interfacial bonding [10]. In the present investigation, the effect of hybrid composites can be seen in Figure 6. The damping peak height of the 100% pure glass fibre composite showed the highest magnitude of tan 6. It is followed by the *Arenga pinnata* hybrid composites and pure *Arenga pinnata* composites. Again, it is not surprising because, with higher fibre volume content in composites, it tends to have lower tan 6 peak height. This would mean there is less energy in the interface area because there is an increase in the interfacial area [9].

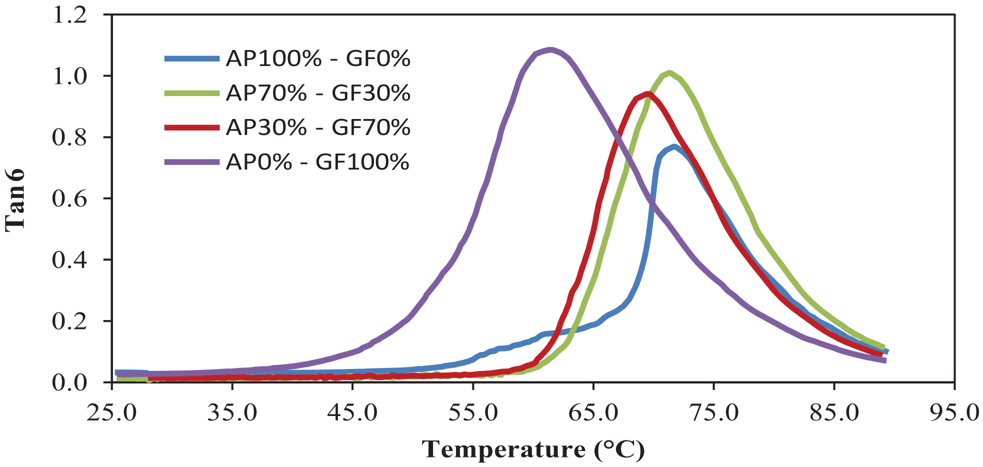

Figure 6: Variation of Damping, Tan ð, with the Temperature of *Arenga pinnata* and Its Hybrid Composites

CONCLUSION

The influence of fibre weight fraction of *Arenga pinnata* and its hybrid composites was successfully investigated. The *Arenga pinnata* fibre composite has better flexural modulus than the glass fibre composites and their hybridised composites. In term of dynamic mechanical analysis, the storage modulus shows a decrease for all the composites near the glass transition temperature. However, there was a sharp fall for the glass fibre composites, suggesting lower thermal resistance than the *Arenga pinnata* fibre and its hybrid composites. The results also indicate that the Arenga pinnata fibre composite has the highest loss modulus peak height and lower tan 6 peak height. It is interesting to see the uses of fibre weight fraction could enhance specific strength and modulus of *Arenga pinnata* composites, which means for the same fibre weight, *Arenga pinnata* composites are even stronger than glass fibre composites. The results also suggest *Arenga pinnata* fibre is a suitable candidate to replace glass fibre in polymer composites as a single reinforcement or being hybridised with other glass fibres in a composite.

ACKNOWLEDGEMENTS

The authors are grateful to the Faculty of Mechanical Engineering, Universiti Teknologi MARA, for funding this project.

REFERENCES

[1] H. N. Dhakal, Z. Y. Zhang, R. Guthrie, J. MacMullen, and N. Bennett, 2013. Development of flax/carbon fibre hybrid composites for enhanced properties. *Carbohydr. Polym., 96*(1), pp. 1–8. DOI: 10.1016/j.carbpol.2013.03.074.

[2] A. Athijayamani, M. Thiruchitrambalam, U. Natarajan, and B. Pazhanivel, 2009. Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite. *Mater. Sci. Eng. A, 517*(1), pp. 344–353. DOI: 10.1016/j.msea.2009.04.027.

[3] M. Jawaid, H. P. S. Abdul Khalil, and O. S. Alattas, 2012. Woven hybrid biocomposites: Dynamic mechanical and thermal properties. *Compos. Part A Appl. Sci. Manuf., 43*(2), pp. 288–293. DOI: 10.1016/j.compositesa.2011.11.001.

[4] F. Sarasini et al., 2016. Damage tolerance of carbon/flax hybrid composites subjected to low velocity impact. *Compos. Part B Eng., 91*(1), pp. 144–153. DOI: 10.1016/j.compositesb.2016.01.050.

[5] M. L. Sanyang, 2016. Recent developments in sugar palm (Arenga pinnata) based biocomposites and their potential industrial applications: A review. *Renewable, 5*(2), pp. 533–549. DOI: 10.1016/j.rser.2015.10.037.

[6] D. O. Bichang'a and H. R. Ayub, 2017. ERect of Fibre Weight Fraction on Mechanical Properties of Woven Sisal Fabric Reinforced Epoxy Composites. *Int. J. Eng. Sci. Invent., 6*(11), pp. 72–75,

[7] Abdullah-Al-Kafi, M. Z. Abedin, M. D. H. Beg, K. L. Pickering, and M. A. Khan, 2006. Study on the mechanical properties of jute/glass fiber-reinforced unsaturated polyester hybrid composites: Effect of surface modification by ultraviolet radiation. *J. Reinf. Plast. Compos., 25*(6), pp. 575–588, DOI: 10.1177/0731684405056437.

[8] J. Flynn, A. Amiri, and C. Ulven, 2016. Hybridised carbon and flax

fiber composites for tailored performance. *Mater. Des., 102*(1), pp. 21–29. DOI: 10.1016/j.matdes.2016.03.164.

[9] H. L. Ornaghi Jr., A. S. Bolner, R. Fiorio, and A. J. Zattera, 2010. Mechanical and dynamic mechanical analysis of hybrid composites molded by resin transfer molding. *J. Appl. Polym. Sci., 118*, pp. 887–896. DOI: 10.1002/app.32388.

[10] L. A. Pothan, Z. Oommen, and S. Thomas, 2003. Dynamic mechanical analysis of banana fiber reinforced polyester composites. *Compos. Sci. Technol., 63*(2), pp. 283–293. DOI: 10.1016/S0266-3538(02)00254-3.