Research Article

Journal of Environmental Nanotechnology

Physical, Mechanical and Thermal Characterization of Areca, Pineapple and Glass Fiber Reinforced Polymer Composites for Aerospace Applications

N. Lenin Rakesh[1*], K. Selvakumar[1] and V. Mohanavel[2]

[1]Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai, TN, India

[2]Centre for Materials Engineering and Regenerative Medicine, Bharath Institute of Higher Education and Research, Chennai, TN, India

Received: 27.07.2024 Accepted: 22.09.2024 Published: 30.09.2024

*leninrakesh.mech@bharathuniv.ac.in

ABSTRACT

In the current scenario, the focus on applying natural fiber-reinforced polymer composites in aerospace applications has increased tremendously due to their attractive characteristics such as lightweight, higher strength-to-weight ratio, good thermal stability at environmental temperatures, resistance to corrosion, sound absorbing capability and increased fuel efficiency. Further, studies on Bi-directionally oriented fiber composites have more advantages than the random or unidirectional orientation, such as uniform stress distribution and improved bonding at the interface. So, the present work focuses on using the Areca, Pineapple Leaf Fiber (PALF) and Glass fiber as the bi-directional fiber mat for reinforcing it into Epoxy polymer. The three different materials were fabricated by changing the fiber type with constant volume fraction and orientation. The martial characterization was done on the fabricated composites in order to evaluate their orientation effectiveness through density, moisture absorption, tensile, impact, hardness and thermal degradation. The bonding relationship was analyzed through a Scanning Electron Microscope. The results showed that the properties obtained were higher for the PALF composite than the areca composites due to the fact that the higher surface area of PALF fibers is confirmed through SEM analysis.

Keywords: Areca fiber; Pineapple leaf fiber; Glass fiber properties; Thermogravimetric analysis.

1. INTRODUCTION

Due to the insufficient supply and price hike of crude oil based products, there is a high demand in the naturally available resources for the use as reinforcement material in composites. There is a high demand for lightweight materials in aerospace industries for their products(Akhil *et al.* 2023). As of now, various fibers are used, but focusing on the environmentally friendly factor, natural fiber composites play a crucial role. The fiber direction in the composites has a major influence on stress transfer across the interface region of the composite laminate (Raja *et al.* 2022; Chandradass *et al.* 2023). The good adhesion between the fiber and the matrix increases the effective interlocking between fiber and matrix. The bi-directional fiber orientation in composites accomplishes the interlocking by reducing the gap or empty spaces and thus improves the stress transfer. The dynamic properties studied on the bidirectional glass fiber reinforced epoxy polymer composites showed that the visco elastic properties such as storage modulus, loss modulus and damping were better when compared to the earlier studies due to the good bonding at the interface region(Arib *et al.* 2004). Natural fibers typically have a hollow structure. Because of this, natural fibers have excellent heat- and sound-absorbing qualities, which affects their application as reinforcing material in composites for aerospace and automotive components. Natural fiber-reinforced composites are used to create components that do not require load-bearing capacity. In aircraft applications, fiber-reinforced composites have a significant impact due to their immunity to corrosion and impact, fail-safe performance, and lower maintenance costs (Mohanavel *et al.* 2022). Parts include pressure vessels, seat rails, landing gear doors, trailing edge panels, business tables, and aircraft wings are examples of components. It is widely acknowledged that the characteristics of the constituent materials, their orientation, and the bonding interaction between them determine the majority of the features of composites (Anand *et al.* 2022). The geometry of the reinforcement (size and form), the volume percentage between the reinforcement and matrix, and the orientation of the fiber with the matrix all have a significant impact on the composite's qualities in addition to the type of reinforcement and matrix materials. The volume or weight fraction of each element is used to calculate the composites' overall attributes (Bakhori *et al.* 2022). Not only is the effect of a single ingredient on the composites' qualities thought to be the most significant factor, but it can also be a readily controlled production variable that modifies the composites' properties(Asim *et al.* 2015).

The main objectives of the research are to enhance the moisture absorption and mechanical and thermal behaviour of epoxy composite by incorporating the bi-directional areca fiber, PALF, and glass fiber mat via conventional associated with compression action with an applied pressure of 100-200 MPa. The effectiveness of bi-directional orientation was analyzed through different material properties such as density, water uptake by the specimen, tensile, impact, hardness, thermal degradation and microstructural properties.

2. EXPERIMENTATION

2.1 Fabrication of Composites

The raw materials used for the fabrication of composites are shown in Table 1. One of the closed mould fabrication processes, namely the compression moulding technique, is used to fabricate the bidirectional oriented natural and glass fiber reinforced composites. The fiber and matrix percentage volume was fixed as 50:50. Initially, the epoxy and hardener mix in the ratio of 10:1 was applied at the bottom of the open mould after applying wax for easy removal of material from the mould. Then the two layers of fiber mat were placed, and again, the resin was poured over the fiber mat. Then, the remaining three layers were placed. Finally, the resin mix was poured over the mat with uniform distribution. Next, the part of the mould was closed, and pressure ranging from 100-200MPa was applied at a temperature of 170-200ºC for 10-15 minutes. It favours better interfacial action between the fiber-matrix. Finally, the pressure was released, and the composite was removed from the mould. Then, the specimens for various material characterization were prepared according to the ASTM standard (Sadek *et al.* 2024) using the vertical cutting machine. The composition and designation of the composite are shown in Table 2.

Table 1. Properties of sterculia foetidaand epoxy resin

Fiber Type	Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)	Water Absorption, (24 Hrs.' at 20ºc)	Reference
Pineapple Leaf Fiber	0.95	290 - 330	5.38 - 9.68	3.1 - 6.9	0.7 - 1.21	BAkhori*et al.* (2022)
Areca	0.7-0.8	147-322	2.3-3.2	3-11	0.8-7.3	HErrera and Alez, (2005)
Glass	2.5	2000-3500 MPa	70-86	2.5-3	-	BAkhori*et al.* (2022)
Epoxy LY556	1.1-1.4	35-100	3-6	1-6	0.1-0.4	HErrera and Alez, (2005)

Table 2. Composition and designation of composites

Sl. No	Composite Laminate Designation	Volume Percentage of Fiber and Matrix (50:50)	
		Fiber	Matrix
1	**AE-A**	Areca	Epoxy
2	**PE-B**	Pineapple Leaf	Epoxy
3	**GE-C**	Glass	Epoxy

Fig. 1: Test specimens prepared according to ASTM standard

2.2 Physical, Mechanical and Thermal Characterization of Composites

The physical properties, such as the density of the composites and moisture intake by the samples every 24 hours, are determined according to the standards ASTM C693 and ASTM D570-98, respectively. The deviations between the calculated theoretical density and the fabricated composite actual density were determined, and it is termed as percentage error. The quality of the bonding between the fiber and the matrix was confirmed with the application of Scanning Electron Microscopic (SEM) analysis. The tensile strength and Young's modulus were calculated according to the standard ASTM D638 using the universal testing machine with a specimen size of 165mm × 19mm × 5 mm dog bone shape. The cross-head speed was maintained at 2mm/min for conducting the test. The energy absorption by the samples during sudden shock load was analyzed using an Izod impact tester according to the ASTM D256 standard. The deformation at the composite surface against steel ball indentation is studied by Rockwell hardness test as per ASTM D785 standard. The HRL scale is used for performing the test for composites. The material loss against the increasing temperature with a constant heating rate is analyzed using the thermogravimetric analysis (TGA) according to the standard ASTM E1131. The composite powder sample of around 8-12 mg was taken, and the temperature ranging from 32ºC to 800ºC was used. The various test samples prepared according to the ASTM standard are shown in Figure 1.

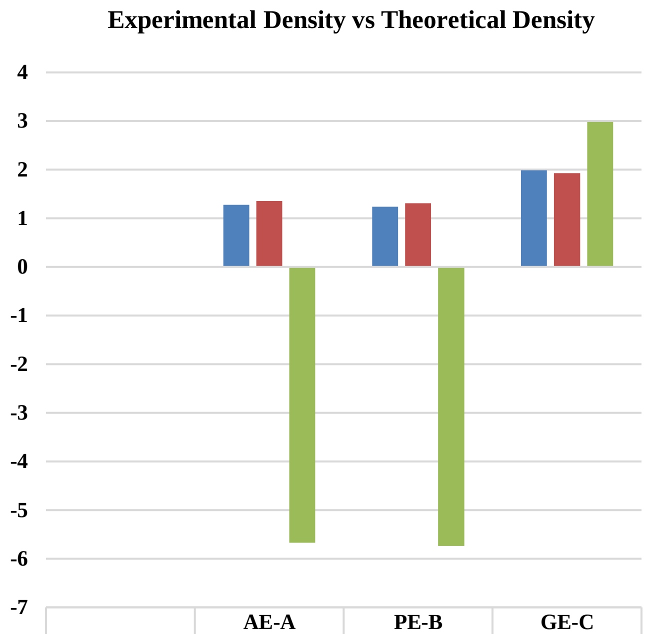
3. RESULTS AND DISCUSSION

Microsoft office Excel 2007 is utilized to represent the graphical results for density, wear, and mechanical properties of composites.

3.1 Physical Properties

3.1.1 Density

Figure 2 shows the results obtained from the density analysis of the composites. The voids present in the composites during the material fabrication have a major influence on the weight of the composites. It is seen in Figure 2 that the fabricated composites obtained a density value almost closer to the theoretical density of the composites. The error between the densities of the present works is proven below as compared to the earlier studies on natural fiber composites (Odusote and Oyewo, 2016). The density analysis performed on the jute/glass/epoxy composites obtained 1.3-1.4 g.cm^3. The glass fiber composites GE-C obtained higher density than the areca and PALF composites due to the higher density value of glass fibers. The quality of the surface finish and uniform distribution of the fiber with the matrix are the factors which affect the voids in composite laminates (Siakeng *et al.* 2018).



		AE-A	PE-B	GE-C
Average Experimental Density of Composite ρc (g/cm3)	0	1.278	1.235	1.988
Theoretical Density of Composites ρc (g/cm3)	0	1.355	1.31	1.93
Percentage Error	0	-5.67	-5.74	2.98

Fig. 2: Percentage error between experimental density and theoretical density

3.1.2 Water Absorption

The moisture content retained in the composites is determined through a water absorption test. The wetness present in the composite component results in loss of adhesion at the interface structure. Thus resulting in the loss of material properties. The moisture results in the present work show less as compared to the hybrid natural fiber reinforced composites fabricated by Sadek *et al.* (2024) and Siakeng *et al.* (2018). The work done on the coir/PALF/epoxy composites obtained in the range 0.75-0.93. This is 55- 80% higher than the present work results. Due to the woven bidirectional fibers, the amorphous contents like hemicellulose, lignin and pectin are removed from the fiber during fiber processing, and it leads to reduced moisture gain in the fabricated composites (Pai & Jagtap, 2015; De Poureset *al.*2024; De Poures *et al.*2024). Figure 3 shows the percentage of Moisture Absorption every 24 hrs.

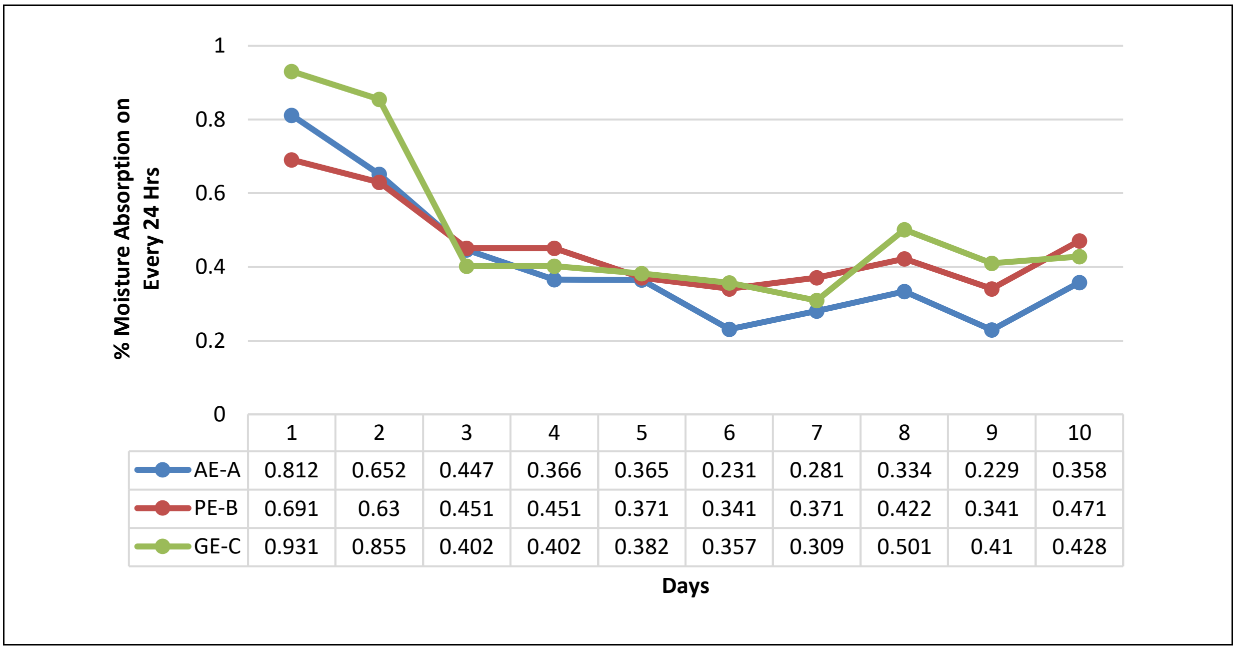


Fig. 3: Percentage of moisture absorption at every 24 hrs

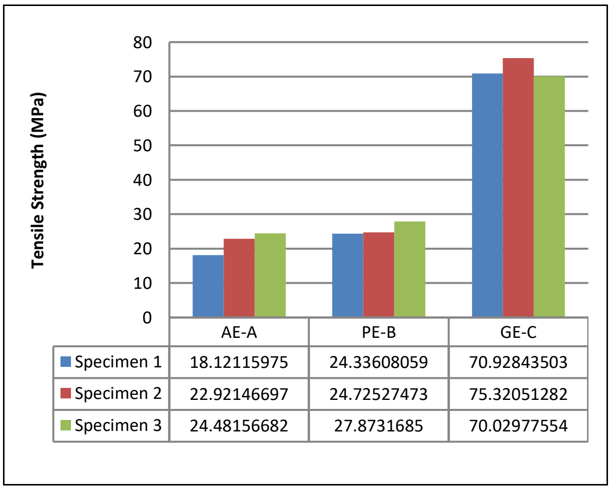


Fig. 4: Tensile strength of composites

3.2 Mechanical Properties

3.2.1 Tensile Properties

A universal testing machine determined the strength of the composites under two equal and opposite forces. The tensile strength and Young's modulus values were calculated from the graph obtained during the test. Three specimens from each composite type are prepared for performing each test. The tensile strength shows that the PALF composite obtained 12-33 % higher tensile strength than the Areca fiber composites, which is seen in Figure 4. It is due to the coarse structure of the PALF fiber within the composites, which is identified in the SEM image of the composite PE-B. Glass fiber mat reinforced epoxy composites GE-C obtained 200% higher strength than the natural fiber composites. It is similar to the work done on the glass fiber and epoxy composites with different volume fractions (Ramesh *et al.* 2022).

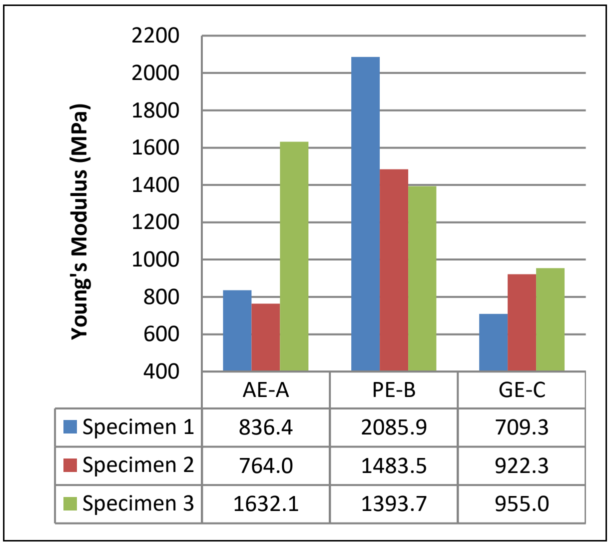


Fig. 5: Tensile modulus or Young's modulus of composites

The Young's modulus of the PALF composites shows (Fig. 5) a higher degree of resistance against the deformation of the material under the tensile load. The strain rate seems to be higher in areca fiber composites than in the samples of PE-B. The increase in the molecular mobility at the fiber and resin interface of the composite sample led to an increase in the deformation, thus resulting in a lower Young's modulus in areca fiber composites (Mittal and Chaudhary, 2019).

3.2.2 Impact Strength

The Izod impact test results are shown in Figure 6. It is seen that the impact strength is almost the same in both the AE-A and PE-B composite specimens, except for small deviations between the values. However when comparing the natural fiber composites with the GE-C composites, there is a larger variation between the energy values. This is due to the higher density and energy absorption behaviour of glass fiber. The bi-directional glass fiber mat has acquired a higher rate of energy absorption capacity due to its finer surface and its ability to have binder-free adhesion properties(Rahman *et al.*2018). The effective stress distribution is also one of the main factors which directly affects the energy absorbed during the sudden striking of the specimens under certain loading conditions. It is evident from the different research work done on the epoxy composites reinforced with various natural fibers such as coir, jute, hemp, flax, and banana, which show values between 11-24 KJ/m^2. These values are less than the present work composites AE-A and PE-B (Cisneros *et al.* 2017).

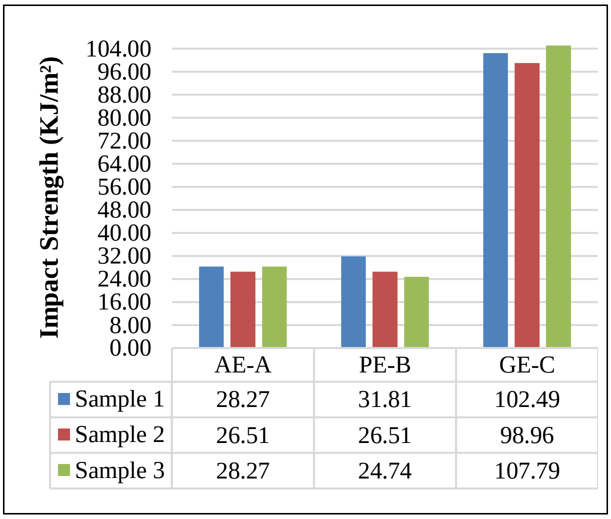


Fig. 6: Impact strength of composites

3.2.3 Rockwell Hardness

Figure 7 shows the ability to resist the indentation by the external load applied to it. The GE-C composites offered a good resistance than the natural fiber composites. As the tendency of the soft protective layer at the top of the surface of the glass fiber causes it to obtain a higher hardness value than the soft surface structure at the outermost region of the natural fibers(Chen *et al.* 2014). The PE-B composites show a higher ability of resistance than the AE-A composites. As discussed in the tensile strength, the PALF fiber provides the coarse surface structure at the interface, which influences the higher hardness than areca fiber composites (De Poures *et al.* 2024; Joshi and Patel, 2022).

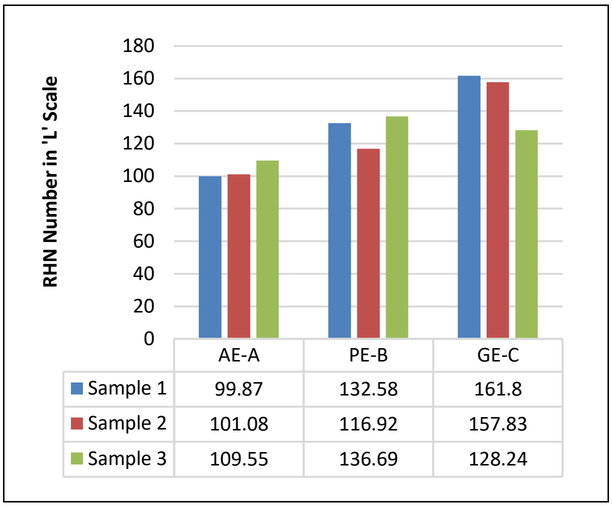


Fig. 7: Rockwell hardness of composites

Table 3. Temperature at different percentage weight loss of the composites

S. No.	Weight Loss %	AE-A	PE-B	GE-C
1	2	120	150	189
2	5	290	293	306
3	10	330	332	355
4	15	351	350	376
5	20	361	362	395
6	30	382	378	410
7	40	412	392	452
8	50	420	410	470
9	60	438	392	488
10	70	457	431	545
11	80	502	540	596
12	90	552	751	625

3.3 Thermogravimetric Analysis

The loss of material during thermogravimetric analysis is shown in Figure 8. Generally, material degradation occurs in the three different periods. A similar phenomenon was obtained for all three composite samples. During the initial stage, the moisture content in the sample was dried out between the temperatures of 300-350ºC. Secondly, the fiber compositions like hemicellulose, pectin, lignin and waxy contents were degraded between the temperatures 350-610ºC. Lastly, the complete material loss occurred beyond 550-610ºC. Glass fiber composites obtained higher thermal stability than natural fiber composites. The weight loss at the different temperatures is shown in Table 3. It is clearly observed that the material loss occurs at higher temperatures in all stages as compared to the work carried out on the flax/epoxy, jute/epoxy, and coir/banana/epoxy composites (Krishnakumar *et al.* 2024; Cisneros-López *et al.* 2017). Removal of amorphous contents during fiber processing increased the thermal stability of the bidirectional fiber-reinforced composites (Aruna *et al.* 2024).

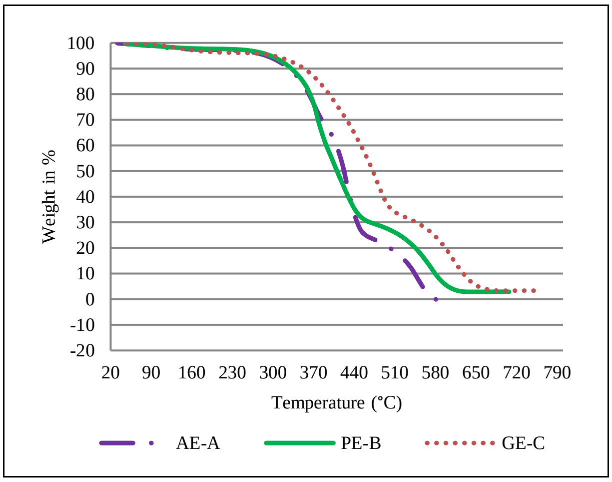


Fig. 8: Thermal degradation of composites

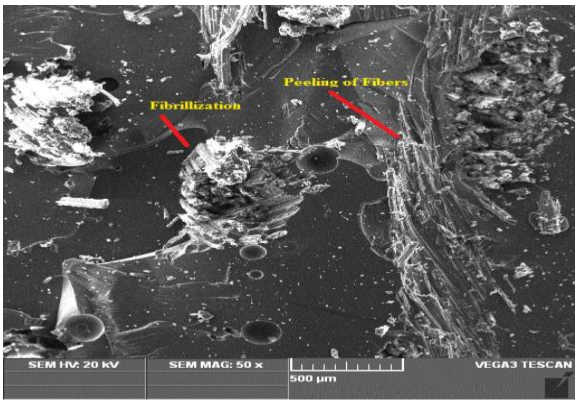


Fig. 9: SEM image of areca fiber reinforced composite

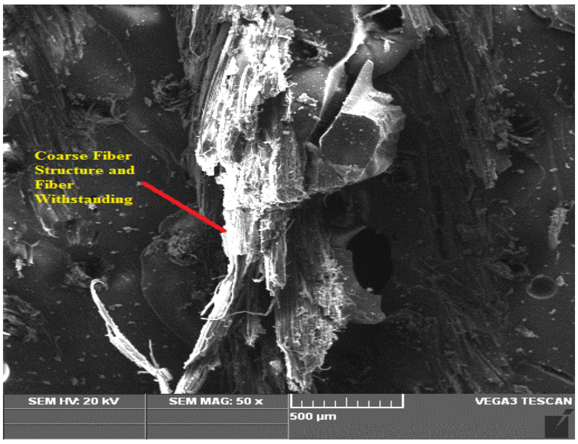


Fig. 10: SEM image of pineapple leaf fiber reinforced composite

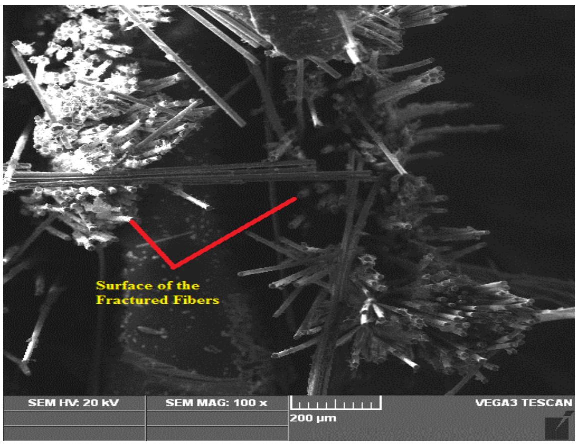


Fig. 11: SEM image of glass fiber reinforced composite

3.4 Scanning Electron Microscopic Analysis

The SEM image obtained at the area of a tensile fractured surface of areca, PALF, and Glass fiber composites are shown in Figures 9, 10, and 11, respectively. It is noted that the areca fiber composite samples fibers were completely peeled off during the test instead of breaking due to the long continuous fiber. Fibrillation also occurs in some regions of the samples as it leads to higher tensile strength. The PALF composite samples show the coarse fiber structure after the breaking of the samples. It improved the resistance against the external load acting on it. The glass fiber surfaces clearly show that their surface shape is not even changed after the breaking of the samples. The protective outer layers were not damaged during the load applied (Shetty *et al.* 2022).

4. CONCLUSION

The research works on the successful fabrication of Areca/Epoxy, PALF/epoxy and Glass/epoxy composites with bidirectional fiber orientation using compression moulding technique. The various test on physical, mechanical and thermal was conducted and properties like density, moisture absorption, tensile, impact and hardness properties were obtained. The following conclusions were drawn from the results obtained on the composites. The PE-B composites obtained higher mechanical properties such as tensile, impact and hardness than the AE-A composites. It is due to the higher surface area of the fiber as compared to the areca fiber. While the physical properties show higher for PE-B due to a larger surface area, the more amorphous contents obtained higher density and moisture absorption than the areca composites. Glass fiber reinforced polymer composites were found to have improved physical, mechanical and thermal properties than the natural fiber composites. The SEM image concluded that the proper distribution of the matrix throughout the bidirectional fiber mat was achieved, and it increased the uniform stress transfer during the load application. The composites reinforced with bi-directionally oriented areca fiber and PALF can be used as the alternative material for automotive applications. Specifically, it was used for automotive front cabin applications. The addition of fillers, fiber surface treatments, and hybridization of fibers further improves the properties.

FUNDING

There is no funding source.

CONFLICT OF INTEREST

The authors declared no conflict of interest in this manuscript regarding publication.

REFERENCES

Akhil, U. V., Radhika, N., Saleh, B., Aravind Krishna, S., Noble, N., & Rajeshkumar, L., A comprehensive review on plant-based natural fiber reinforced polymer composites: fabrication, properties, and applications, *Polym. Compos.*, 44(5), 2598-2633 (2023). https://doi.org/10.1002/pc.27274

Anand, P. B., Lakshmikanthan, A., GowdruChandrashekarappa, M. P., Selvan, C. P., Pimenov, D. Y. and Giasin, K., Experimental investigation of effect of fiber length on mechanical, wear, and morphological behavior of silane-treated pineapple leaf fiber reinforced polymer composites, *Fibers*, 10(7), 56 (2022). https://doi.org/10.3390/fib10070056

Arib, R. M. N., Sapuan, S. M., Hamdan, M. A. M. M., Paridah, M. T. and Zaman, H. M. D. K., A literature review of pineapple fibre reinforced polymer composites. *Polym. Compos.,*12(4), 341-348 (2004). https://doi.org/10.1177/096739110401200408

Aruna, M., Manivannan, S., Kumar, A., Vignesh Kumar, M., Chandramohan, P., Lakshmanan, S., & Venkatesh, R., Impact of Silicon Carbide Particle on the Behavior of Coir Fiber-Incorporated Polypropylene Hybrid Composite. *J. Inst. Eng. India Ser. D.*, (2024). https://doi.org/10.1007/s40033-024-00734-4

Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M. R. and Hoque, M. E.. A review on pineapple leaves fibre and its composites, *Int. J. Polym. Sci.*, (1), 950567 (2015). https://doi.org/10.1155/2015/950567

BA, P., Shetty, P. B., N, V., HV, S. and Singh Yadav, S. P., Mechanical properties and water absorption behaviour of pineapple leaf fibre reinforced polymer composites. *Adv. Mater. Process. Technol.*, 8(2), 1336-1351 (2022). https://doi.org/10.1080/2374068X.2020.1860354

Bakhori, S. N. M., Hassan, M. Z., Bakhori, N. M., Rashedi, A., Mohammad, R., Daud, M. Y. M. and Kumar, A., Mechanical properties of PALF/Kevlar-reinforced unsaturated polyester hybrid composite laminates, *Polymers*, 14(12), 2468 (2022). https://doi.org/10.3390/polym14122468

Chandradass, J., Thirugnanasambandham, T., Amutha Surabi, M., Baskara Sethupathi, P. aand Rajendran, R., Development of Asbestos Free Aramid Fibre based Friction lining Material for Automotive Application, *SAE Technical Papers*, (2023). https://doi.org/10.4271/2023-28-0122

Cheng, F., Hu, Y. and Yuan, J. (2014). Preparation and characterization of glass fiber-coir hybrid composites by a novel and facile Prepreg/Press process.*Fiber Polym.*,15, 1715-1721. https://doi.org/10.1007/s12221-014-1715-5

Cisneros-López, E. O., González-López, M. E., Pérez-Fonseca, A. A., González-Núñez, R., Rodrigue, D., & Robledo-Ortíz, J. R., Effect of fiber content and surface treatment on the mechanical properties of natural fiber composites produced by rotomolding. *Compos. Interfaces,* 24(1), 35-53 (2017). https://doi.org/10.1080/09276440.2016.1184556

De Poures, M. V., Shariff, J., Chakravarthy, K. S., Rao, K. S., Prasad, V. S., Reddy, Y. S. and Saveetha, G., Influence of Silica Nanoparticles on Mechanical Properties of Bast Fibers Made Epoxy Composite via Injection Moulding Route, *J. Inst. Eng. India Ser. D.*, 1-6 (2024).. https://doi.org/10.1007/s40033-024-00738-0

De Poures, M. V., Sudhir Chakravarthy, K., Jabihulla Shariff, M. D., Srinivasa Reddy, Y., Siva Prasad, V., Sreenivasa Rao, K. and Kishore, K., V. Excellence of Nano SiC on Mechanical Behaviour of Low Density Polyethylene Hybrid Nanocomposite, *J. Inst. Eng. India Ser. D* (2024). https://doi.org/10.1007/s40033-024-00713-9

Herrera-Franco, P. and Valadez-Gonzalez, A., A study of the mechanical properties of short natural-fiber reinforced composites, *Compos. B Eng.,* 36(8), 597-608 (2005). https://doi.org/10.1016/j.compositesb.2005.04.001

Joshi, S. and Patel, S., Review on mechanical and thermal properties of pineapple leaf fiber (PALF) reinforced composite. *J. Nat. Fibers.*, 19(15), 10157-10178 (2022). https://doi.org/10.1080/15440478.2021.1993487

Krishnakumar, S., Mohanavel, V., Venkatesh, R. and Balasubramanian, K., Enhancement of tribology behaviour by the addition of different fiber length of pineapple fiber reinforced polyester composite, *J. Mech. Sci. Technol.,* 38(1), 201-206 (2024). https://doi.org/10.1007/s12206-023-1217-8

Mittal, M. and Chaudhary, R., Biodegradability and mechanical properties of pineapple leaf/coir Fiber reinforced hybrid epoxy composites, *Mater. Res. Express,* 6(4), 045301 (2019). https://doi.org/10.1088/2053-1591/aaf8d6

Mohanavel, V., Suresh Kumar, S., Vairamuthu, J., Ganeshan, P. and Nagaraja Ganesh, B., Influence of stacking sequence and fiber content on the mechanical properties of natural and synthetic fibers reinforced penta-layered hybrid composites, *J. Nat. Fibers,* 19(13), 5258-5270 (2022). https://doi.org/10.1080/15440478.2021.1875368

Odusote, J. K. and Oyewo, A. T., Mechanical properties of pineapple leaf fiber reinforced polymer composites for application as a prosthetic socket, *J. Eng. Technol.,* 7(1), 125-139 (2016). https://doi.org/10.1016/j.matdes.2004.11.009

Pai, A. R. and Jagtap, R. N., Surface morphology & mechanical properties of some unique natural fiber reinforced polymer composites—A review. *J. Mater. Environ. Sci.,* 6(4), 902-917 (2015).

Rahman, M., Das, S. and Hasan, M., Mechanical properties of chemically treated banana and pineapple leaf fiber reinforced hybrid polypropylene composites, *Adv. Mater. Process. Technol.,* 4(4), 527-537 (2018). https://doi.org/10.1080/2374068X.2018.1468972

Raja, T., Mohanavel, V., Ravichandran, M., Kumar, S. S., Albaqami, M. D., Alotabi, R. G. and Murugesan, M., Dynamic mechanical analysis of banyan/ramie fibers reinforced with nanoparticle hybrid polymer composite, *Adv. Polym. Technol.,* 2022(1), 1560330 (2022). https://doi.org/10.1155/2022/1560330

Ramesh, M., Jafrey Daniel James, D., Sathish Kumar, G., Vijayan, V., Raja Narayanan, S. and Teklemariam, A., Synthesis and characterization of banana and pineapple reinforced hybrid polymer composite for reducing environmental pollution, *Bioinorg. Chem. Appl.,* 2022(1), 6344179 (2022). https://doi.org/10.1155/2022/6344179

Sadek, M. G., Abdellah, M. Y. and Abdel-Jaber, G. T., A Review on Properties, Applications and Feasibility Study of Date Palm Fiber-Reinforced Polymer Composites, SVU-Int. *J. Eng. Sci. Appl.,* 5(2), 50-61 (2024). https://doi.org/10.21608/SVUSRC.2024.258614.1171

Siakeng, R., Jawaid, M., Ariffin, H. and Sapuan, S. M., Thermal properties of coir and pineapple leaf fibre reinforced polylactic acid hybrid composites, *IOP Conf. Ser. Mater. Sci. Eng.,* 368, 012019 (2018). https://doi.org/10.1088/1757-899X/368/1/012019