PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 1 (2025) p. 363-375
https://publisher.uthm.edu.my/periodicals/index.php/peat

Improvement of Sound Acoustic and Compressive Strength of Hybrid Polymer Composites (HPCs)

Siti Aminah Ab Malek[1], **Wan Amizah Wan Jusoh**[1]*

[1] *Department of Civil Engineering Technology, Faculty of Engineering Technology,*
Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, Malaysia

*Corresponding Author: amizah@uthm.edu.my

DOI: https://doi.org/10.30880/peat.2025.06.01.039

Article Info

Received: 19 January 2025
Accepted: 06 February 2025
Available online: 30 April 2025

Keywords

Hybrid Polymer Composites, Pineapple Leaf Fiber, Epoxy Resin, Sustainable Materials, Acoustic Properties

Abstract

This study represents the sound acoustic and compressive properties of the experimentally investigated PALF/polyester hybrid polymer composite with an epoxy resin matrix for sustainable engineering applications. The morphological analysis was done by Scanning Electron Microscopy, and X-ray diffraction was performed for calculating the amorphous and crystalline indices of the materials. Identification of the chemical bonding characteristics was extended using FTIR spectroscopy. Tests carried out in this study used HPCs with variable layers of PALF and polyester fibre mats that were prepared in control, one, two, and three layers in order to investigate their characteristics in terms of sound absorption by the Sound Reduction Index test and their mechanical performance through compressive strength tests at 5 mm/min. These include analysis of physical properties, determining the mechanical behavior, and optimization aimed at getting improved hybrid composite performances. A comparative study regarding acoustic and compressive properties was made to assess their suitability for diversified, sustainable engineering applications. The results obtained in the present work provide an insight into the mechanical properties and eco-friendliness of PALF-and-polyester-based hybrid composite materials, which will be an efficient platform for the development of green and durable engineering applications.

1. Introduction

The economy and sustainability of natural fibers, including jute, kenaf, cotton, flax, and hemp, have drawn focus for the development of polymer composites. Renewable fibers possess several advantages, such as low density, biodegradability, low cost, and improved thermal and insulation properties. Another favorable factor is that much lower energy is required for the processing of natural fiber-based composites. These fibers improve mechanical properties, including tensile strength, stiffness, flexural strength, and elongation at break when used with a binder matrix [1]. Reinforcement of natural fibers into polymer composites is in line with global sustainability goals according to the United Nations Sustainable Development Goals, more particularly SDG 11, on making cities and human settlements inclusive, resilient, safe, and sustainable. For instance, hybrid polymer composite optimization with PALF and polyester fibers impregnated with epoxy resin has been one such step in creating durable, light, and sustainable building material [2].

Hybrid polymer composites are composite materials that combine the advantages of more than one kind of fibre, matrix element, or particle with the purpose of ensuring maximum performance by using the best qualities of each component. Among the main advantages of such composites are overcoming the disadvantages of single-component systems and the combination of cost-efficiency and ecological friendliness of natural fibres with improved durability from synthetic fibres. [3]. Among all the natural fibers, PALF has a high percentage of cellulose and a low microfibrillar angle, which provides high tensile properties [4]. HPCs exhibit excellent toughness, thermal stability, and acoustic insulation by reinforcing with polyester fibers and epoxy resin and are suitable for various applications. The incorporation of recycled thermoplastics into the PALF would minimize waste and conserve natural resources. It is also cheaper compared to the conventional material. This will contribute to global sustainability, providing a hazard-free environment and processing advanced materials for the circular economy and resource efficiency.

HPCs represent an innovative means of material development, and the property enhancements offered have opened a wide field in construction and manufacturing. Though promising, few studies have focused on the optimization and characterization of PALF reinforced with polyester fiber and combined with an epoxy resin matrix. In view of the fact that agricultural waste from pineapple production is continuously growing in Malaysia, the application of PALF addresses not only sustainability concerns but also reduces environmental impacts. Epoxy resin is widely used because of its excellent mechanical properties. It still tends to exhibit low durability under severe environmental conditions. It can be improved by the addition of PALF, thus making it even more eco-friendly and resistant as a material. The intention is to analyze the physical and mechanical properties of these HPCs and provide optimization in composition for better performance and sustainability.

2. Material and Methods

2.1 Materials

The materials used in this study are Epoxy Resin, Pineapple Leaf Fiber (PALF), and Polyester Fiber, as shown in Fig.1. Epoxy resin, a thermosetting polymer, was chosen as the matrix because of its superior mechanical strength and chemical resistance. Mixed with a curing agent in a 3:1 ratio, the liquid resin turned into a complex matrix. The pineapple leaf is a natural fibre with excellent stiffness and strength-to-weight ratio, hence the reason for its selection in this work. Polyester fibre is a synthetic reinforcement added to the hybrid composite to enhance its structural integrity and complement the properties of PALF. Table 1 summarizes prior research on composite materials.

(a) **(b)** **(c)**

Fig. 1: Materials (a) Epoxy resin and hardener (b) PALF (c) Polyester

Table 1: Previous studies on the application of mat polymer composites

Author, Year	Type of Raw Material	Type of Resin	Resin and Hardener Ratio	Mat Layer Ration	Fabrication Method
[5]	Twill E-Glass Fiber, Sisal Fiber	Epoxy Resin	10:1	1:0	Hand Lay-Up
[6]	Sisal Fiber	Epoxy Resin	10.1	1:0	Hand Lay-Up
[7]	Abaca, Rubber	Epoxy Resin	10:1	-	Hand Lay-Up
[8]	Coir, E-Glass, Synthetic Fabric	Epoxy Resin	2:1	-	Hand Lay-Up
[9]	Sugar Palm Fiber, Glass Fiber	Epoxy Resin	3:1	-	Hand Lay-Up
[10]	Bamboo Fiber	Epoxy Resin	3:1	-	Fiber Extraction Method
[11]	Jute, PALF, Glass Fiber	Polyester, Epoxy Resin	-	1:1:1	Hand Lay-Up
[12]	Jute Fiber, Glass Fiber	Epoxy Resin	100:0.7	1:0, 1:1, 1:2, 2:1	Hand Lay-Up

2.2 Methods

As described in this study, pineapple leaf fiber (PALF) and polyester fiber with epoxy resin as a matrix were used for the hybrid polymer composites (HPCs). The methodology involves two main types of evaluation physical properties and mechanical properties. SEM were done to assess the surface morphology and chemical composition of the material, respectively. The FTIR was performed in order to identify the functional group and the chemical interactions that occurred, while the XRD analysis was done in order to establish crystallinity diffraction peaks for Epoxy Resin, PALF, and Polyester were recorded. Meanwhile, compressive strength tests and sound acoustic analysis are other experimental works to evaluate the HPCs' characteristics. The flow chart of the study, based on the aim, will consist of stages outlined in Fig. 2.

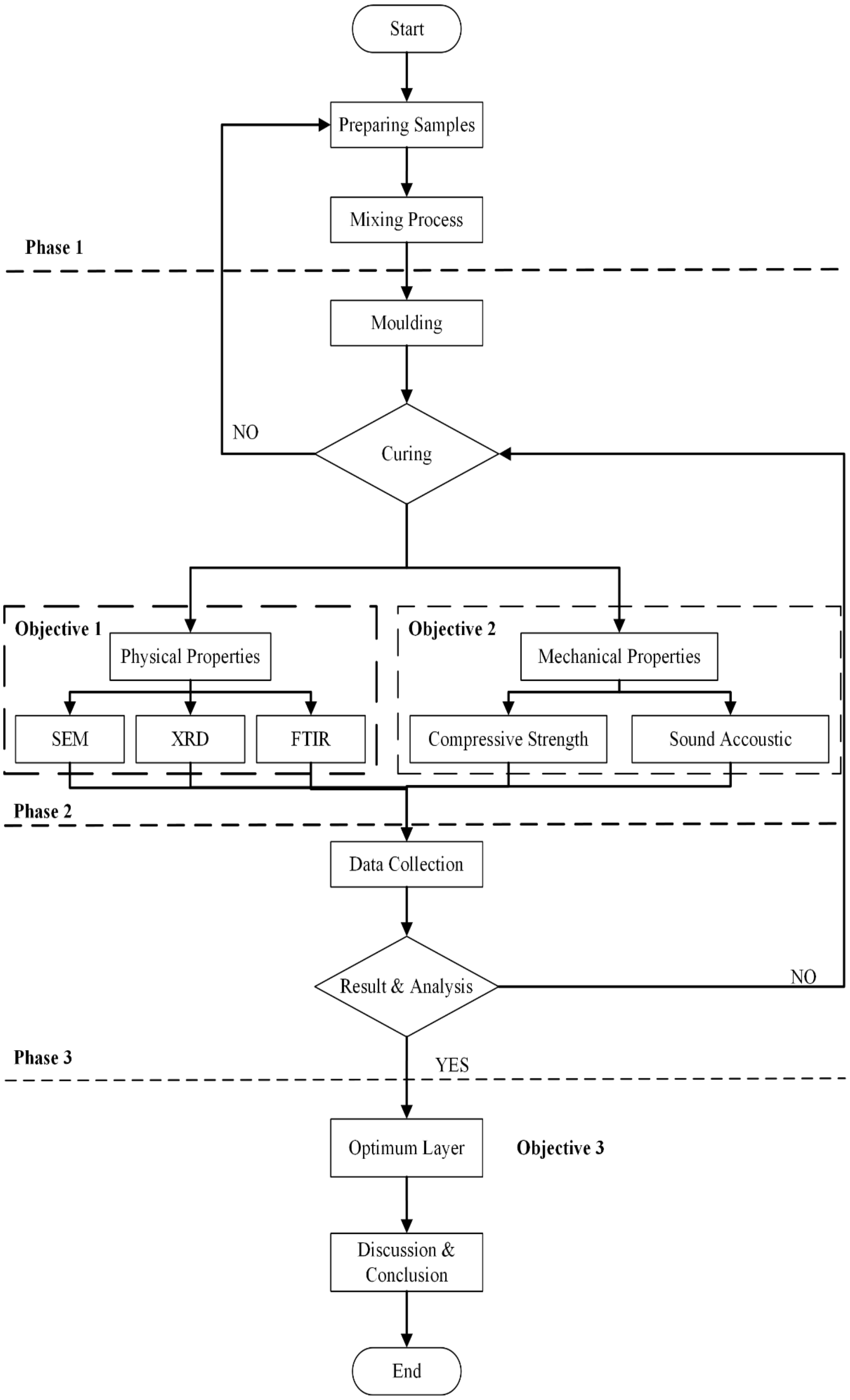


***Fig. 2*:** Flow Chart of the study

2.3 Reference Code and Sample Testing

The physical properties of HPC materials containing epoxy, PALF, and polyester fibre were analyzed by using Scanning Electron Microscopy, X-ray diffraction, and Fourier Transform Infrared Spectroscopy techniques. By using SEM, it was possible to visualize morphologies and chemical structures on material surfaces. On the other hand, functional groups and the interaction of chemicals in the composites could be identified by using FTIR analysis. The material's crystallinity was identified using XRD analysis. Obtaining diffraction peaks for specific epoxy resin, PALF, and Polyester was determined. In this regard, the mechanical tests were conducted with the aim of testing samples based on their tensile strength and modulus of samples. Table 2 presents the reference codes utilized during the test. All samples employed in performing the physical as well as the mechanical are reported in Tables 3 and 4.

Table 2: Reference Code

Testing	Standard Code
SEM	ASTM E2809-22
FTIR	ASTM F3419-22
XRD	ASTM D7653-18
Compressive Strength	ASTM D695
Sound Acoustic	ASTM 423; ISO354

Table 3: Number of samples for physical properties

Testing	Type of Sample	Sample Form	Total
SEM	PALF	Fiber	1
	Polyester	Fiber	1
	Epoxy	Hard Mixture	1
XRD	PALF	Powder	1
	Polyester	Fiber	1
	Epoxy	Hard Mixture	1
FTIR	PALF	Powder	1
	Polyester	Fiber	1
	Epoxy	Hard Mixture	1
		Total Samples	9

Table 4: Number of samples for mechanical properties

Types of Samples	Proportion of Fiber Layer (%)		Ratio for Epoxy and Hardener	No of Fiber Layer	Experimental Testing (Sample)	
	PALF	Polyester			Sound Acoustics	Compressive Strength Test
Control	50	50	3:1	0	1	1
	50	50	3:1	0	1	1
	50	50	3:1	0	1	1
1 Layer	50	50	3:1	1	1	1
	50	50	3:1	1	1	1
	50	50	3:1	1	1	1
2 Layer	50	50	3:1	2	1	1
	50	50	3:1	2	1	1
	50	50	3:1	2	1	1
3 Layer	50	50	3:1	3	1	1
	50	50	3:1	3	1	1
	50	50	3:1	3	1	1
				Total Sample	12	12

2.3.1 Scanning Electron Microscopy (SEM)

SEM analysis was used to study the surface fractures and composition of the Epoxy, PALF, and Polyester materials. Figure 3 show the characterization was done in the COXEM EM-30 AX PLUS SEM machine. Consequently, all specimens were sputter-coated for 15 minutes with a thin layer of gold (Au) using the Quorum Q150R S, which enhances the conductive property. The acceleration voltage of the electron beam was 20 kV, and the procedures were made according to the ASTM E2809-22 guidelines about the study of morphological characteristics by means of electron microscopy. Images were captured at various magnifications, labelled accordingly, and with scale bars included. Energy-dispersive spectroscopy (EDS) was used to determine the elemental composition of the samples.

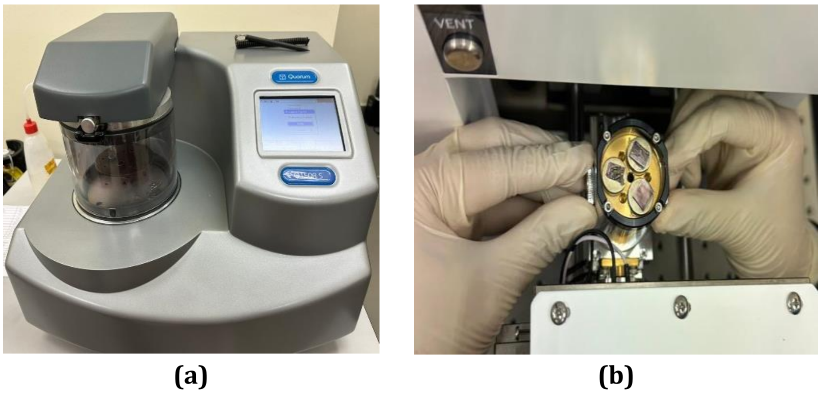

(a) (b)

Fig. 3: SEM Testing (a) Coating with gold (AU) (b) Sample in COXEM machine

2.3.2 X-Ray Diffraction (XRD)

X-ray Diffraction (XRD) analysis was done to determine the crystallographic structure and chemical composition of Epoxy, PALF, and Polyester. The tests were done on the D2 Phaser XRD machine as shown in figure 4. Testing was performed following the ASTM F3419-22 standard that details the procedure for the XRD analysis. Scanning parameters have been set using Cu-Kα radiation as the X-ray source.

(a) (b)

Fig. 4: XRD Testing (a) Sample placed in XRD machine (b) Data was recorded using Bruker D2 Phaser

2.3.3 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was used to analyze the molecular structure and composition of Epoxy, PALF, and Polyester. Tests were carried out on the FTIR spectrometer as shown in figure 5 according to ASTM D7653-18. The adopted setting for the spectrometer wavenumber ranges from 4000 to 400 cm^{-1} and with 4 cm^{-1} resolution. Scanning was done, after which the Absorbance Spectra was recorded.


(a) (b) (c)

Fig. 5: FTIR Testing (a) Epoxy Resin (b) PALF (c) Polyester Fiber

2.3.4 Compressive Strength Test

The compressive strength of HPC specimens such as control sample, one-layer PALF-Polyester mat, two-layer PALF-Polyester mat, and three-layer PALF-Polyester mat was determined in which epoxy resin was used as the matrix for the HPCs. The tests in rectangular specimens were performed according to the ASTM D695 standard by using 150 mm × 13 mm × 20 mm. Each specimen was subjected to compressive loading with a constant speed of 5 mm/min until failure along the central longitudinal axis as shown in figure 6. Compressive strength at failure was calculated based on the recorded data.

Fig. 6: Position the sample parallel to the surface between the plate during compressive test

2.3.5 Sound Acoustic

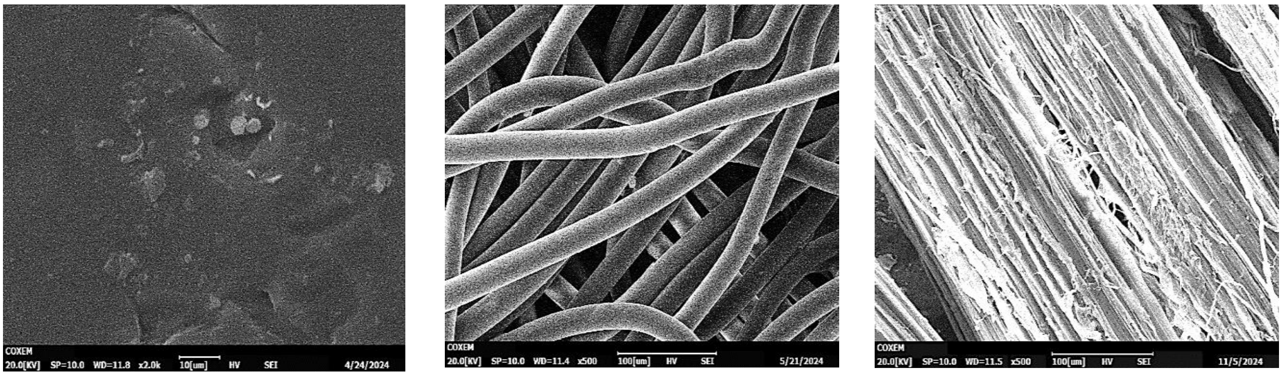
The acoustic tests were performed to find out the sound reduction index of the HPC specimens. The tested samples included one control specimen and HPCs which were reinforced with one, two, and three layers of PALF-Polyester mats using the epoxy resin as the matrix. For the test, rectangular specimens with dimensions of 300 mm × 300 mm × 20 mm were prepared. It involved a test method following the measures of ASTM 423 and ISO 354 for accuracy and reliability. Figure 7 present the acoustic box, sound level meter and prepare the monotone sound for sound acoustic test.

Fig. 7: Monotone sound and sound level meter for sound acoustic test

3. Results and Discussions

3.1 Morphology analysis

SEM analysis gave a detailed morphology of the surface of epoxy, PALF, and polyester fibre, as shown in Figure 8. The smooth and transparent epoxy resin had some bubbles, probably due to the uneven mix during the preparation of the resin. Such smooth texture will ensure reinforcement materials are perfectly embedded. Since PALF is a natural fiber, the rough and irregular surface reflected complex microstructures, enhancing the bonding with epoxy resin and improving strength in the composite. On the other hand, polyester fiber showed a smooth, elongated, twisted structure with high alignment, which imparts flexibility and toughness to the composite. Further, the roughness of PALF can help in good adhesion to the matrix; a smooth and aligned structure balances its flexibility and toughness upon combination with HPCs. Consequently, this will result in an optimization of the mechanical properties of the composites resulting from interactions among the different materials, thus improving strength, durability, and structural integrity.

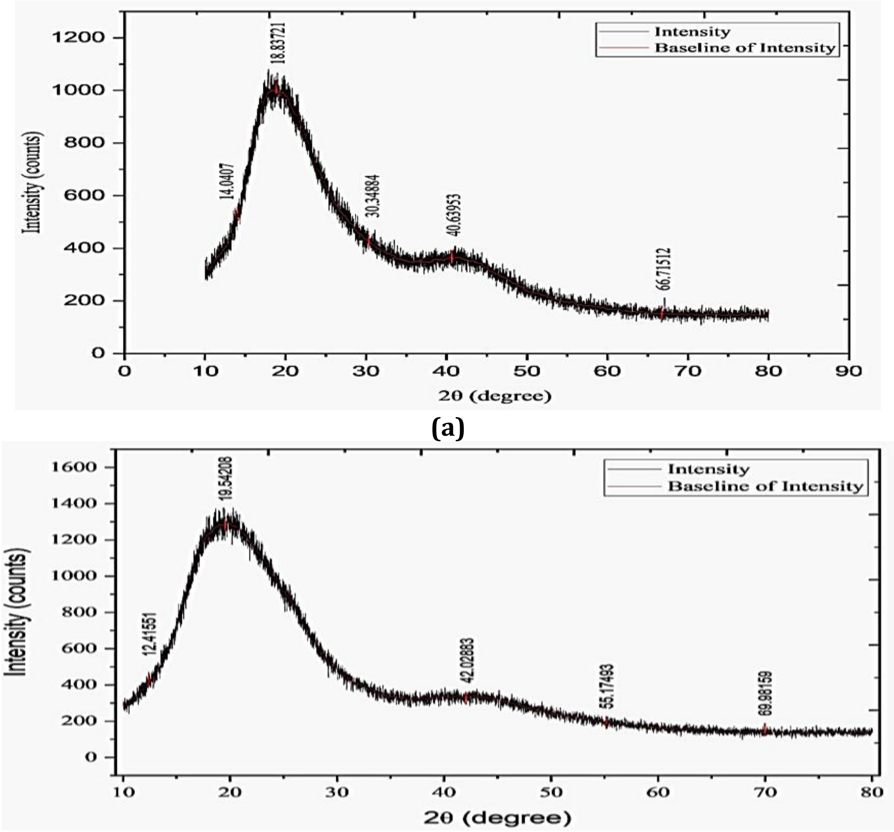


(a) **(b)** **(c)**

Fig. 8: Morphology surface (a) Epoxy (b) Polyester Fiber (c) Pineapple Leaf Fiber (PALF)

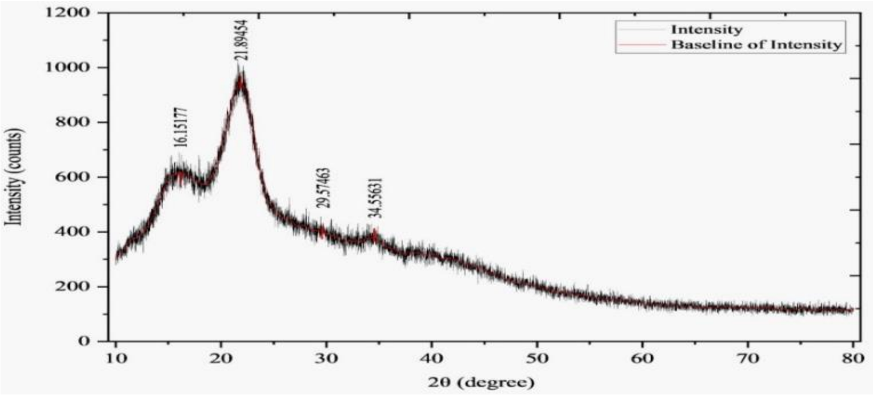
3.2 Amorphous and Crystallinity Index

The XRD analysis of the epoxy resin, polyester fibre, and PALF was used to confirm their crystalline nature through sharp and well-defined peaks, as can be seen in Figure 9. The prominent peaks in the case of epoxy resin occurred at 14.40°, 18.84° (highest intensity, indicating the dominant phase). The peak height at 30.35°, 40.70°, and 66.72° was lower by comparison. Thus, polyester fibre had the main phase uppermost peak at 19.54° while less-intensity peaks at 12.42°, 42.03°, 55.17°, and 69.98°. On the other hand, the most intense peak at 21.89°, with other smaller peaks at 16.15°, 29.57°, and 34.55°, corresponded to PALF in its XRD pattern. These sharp peaks confirm the crystallinity of all materials. The composite is both crystalline and amorphous; the rutile phase and crystalline cellulose structures are evident between 10° and 50° [13]. Alkaline treatment improved crystallinity, reduced amorphous content, and thus improved mechanical properties. Table 5 Crystallinity index values for each material.



(a)

(b)



(c)

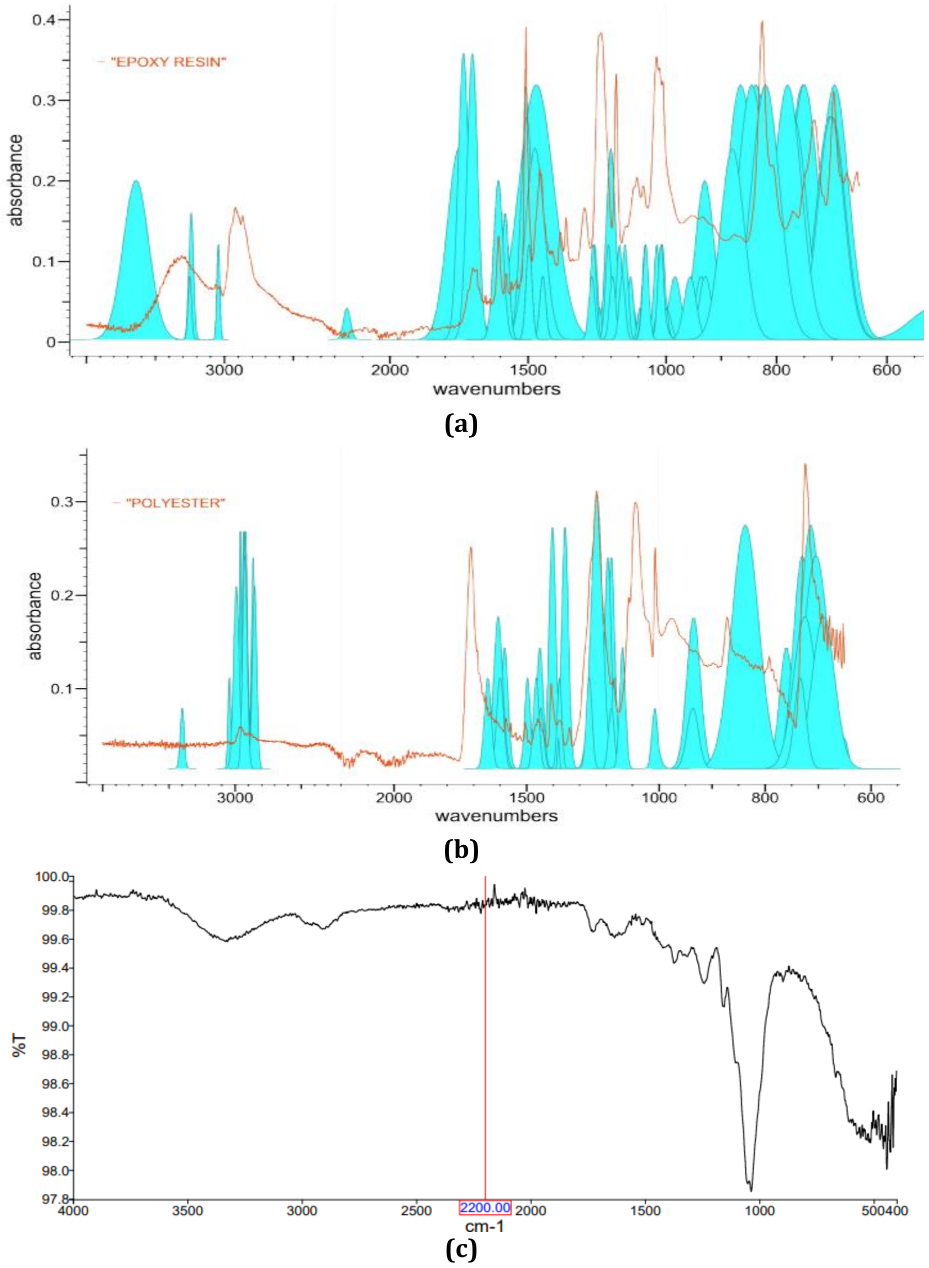
Fig. 9: XRD Analysis (a) Epoxy (b) Polyester Fiber (c) Pineapple Leaf Fiber (PALF)

Table 5: Crystallinity Index of the HPCs materials

Material	Area of crystalline peaks	Total area of crystalline peaks	Area of crystalline and amorphous peaks	Crystallinity Index (%)
Epoxy	1601.05 5917.13 1817.80 1455.88 195.44	10987.31	17703.72	62.06
Polyester Fiber	947.50 10358.01 1421.73 416.43 136.37	13280.05	21543.88	61.64
PALF	1452.74 3392.19 897.51 1072.47	6814.91	14073.92	48.42

3.3 Chemical Bonding

The FTIR analysis in Figure 10 of epoxy resin, polyester fibre, and PALF. For the epoxy resin, the broad peaks in the range of 3000–3500 cm^{-1} are for the stretching vibration of O-H, probably due to residual moisture or hydroxyl groups that did not react; the peak at 1600–1700 cm^{-1} may be due to unreacted epoxide groups. Strong bands in the region of 1200–1300 cm^{-1} confirm C-O stretching, representing epoxy groups, and further vibrations occur between 800–1000 cm^{-1} due to aromatic groups. On polyester fibre, peaks in the region between 3000–2800 cm^{-1} refer to C-H stretching from aliphatic hydrocarbons; a strong peak at 1750–1720 cm^{-1} confirms the C=O stretching of ester groups. Vibrations between 1300–1000 cm^{-1} confirm the ester functionality and the aromatic C-H bending occurs between 800–600 cm^{-1}.PALF analysis presented peaks at 3400 cm^{-1} due to -OH groups, 1700 cm^{-1} due to C=O groups, and 2900 cm^{-1} due to C-H stretching of natural fibres. FTIR confirms that all these materials have different chemical structures with unique properties, which is so essential in composite applications.



(a)

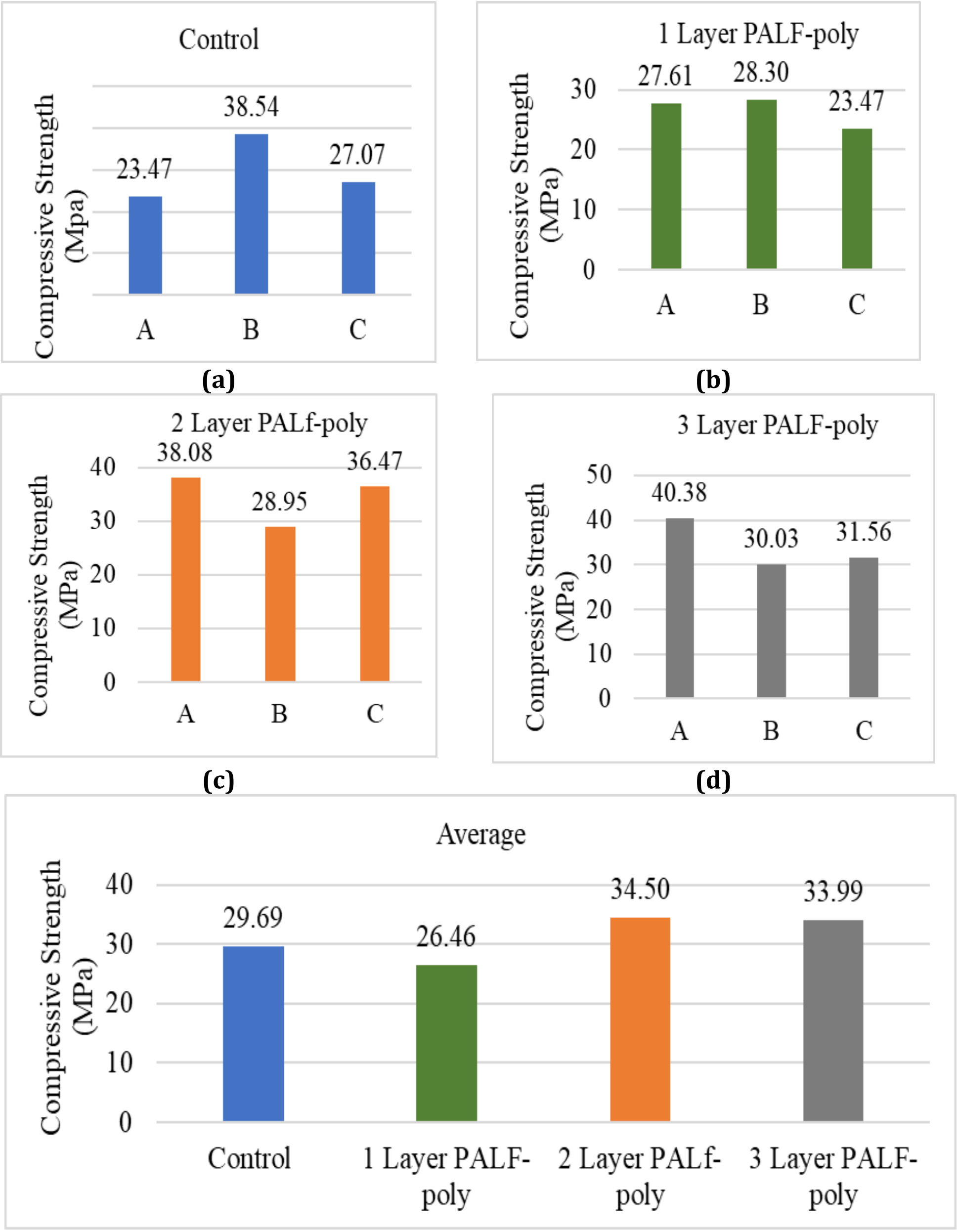
(b)

(c)

Fig. 10: FTIR spectrometry with silence solution under spectrum of 4000cm^{-1} to 400cm^{-1} of (a) Epoxy (b) Polyester Fiber (c) Pineapple Leaf Fiber (PALF)

3.4 Compressive Strength

The compressive strength test was conducted for the specimen dimensions of 150 × 13 × 20 mm for control, 1 Layer, 2 Layer, and 3 Layer PALF-poly configurations. In each configuration, three samples were tested; a total of 12 samples from all configurations were tested. Control samples gave compressive strengths of 23.47 MPa, 38.54 MPa, and 27.07 MPa, averaging 26.69 MPa. For the 1 Layer PALF-poly, the compressive strengths were 27.61 MPa, 28.30 MPa, and 23.47 MPa, resulting in an average of 26.46 MPa. The 2 Layer PALF-poly samples had 38.08 MPa, 28.95 MPa, and 36.47 MPa and gave an average of 34.50 MPa. For 3-layer PALF-poly samples, the compressive strength recorded was 40.38 MPa, 30.03 MPa, and 31.56 MPa, thus providing an average of 33.99 MPa. Consequently, the 2-layer PALF-poly configuration had the highest compressive strength with an average of 34.50 MPa. These results reflected that the addition of layers of PALF increased the compressive strength of epoxy resin, thus making these HPCs suitable for high-strength applications. Compressive strength test data are shown in Figure 11.

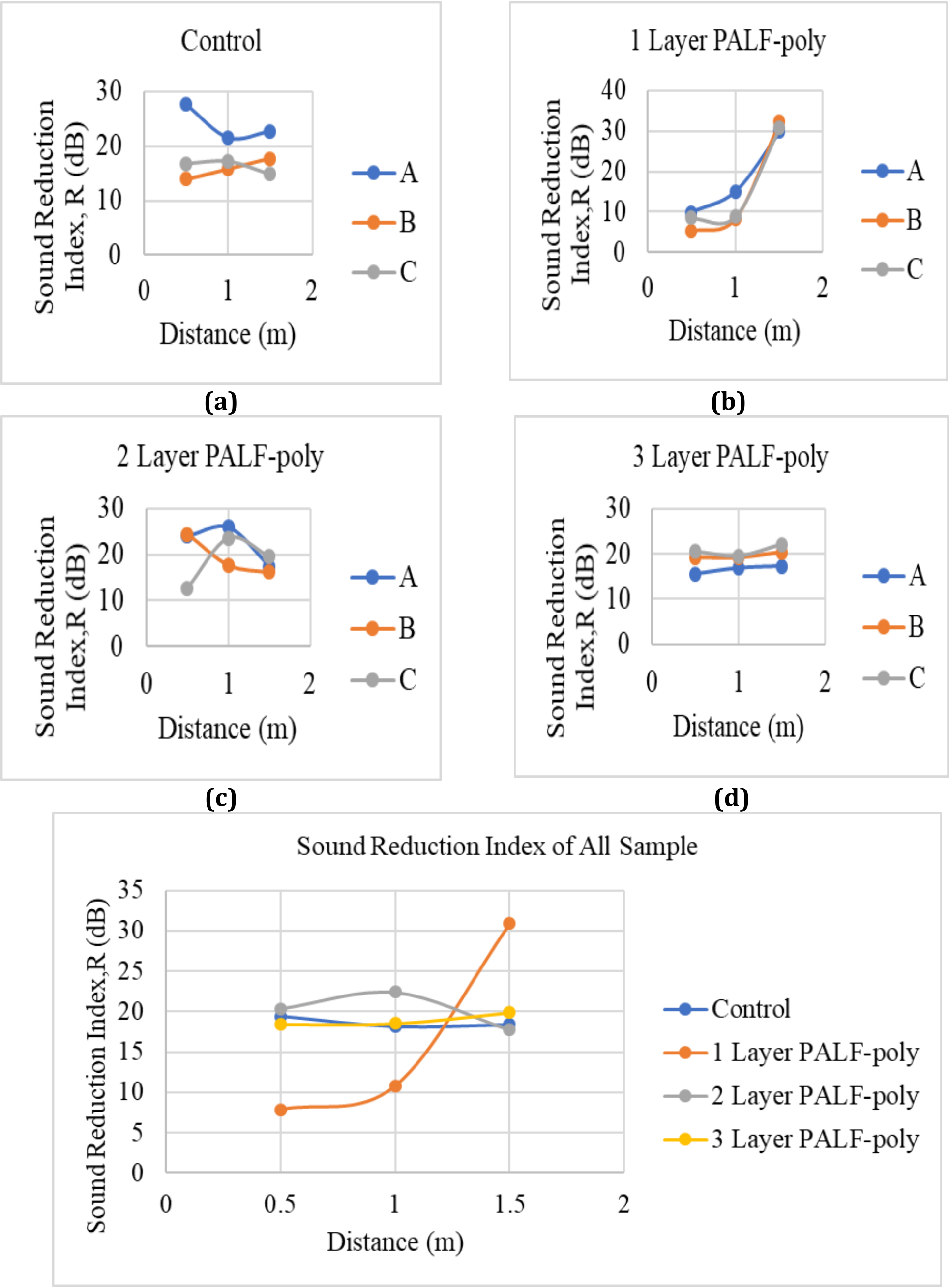


(a) (b) (c) (d) (e)

Fig. 11: Compressive Strength (a) Control Sample (b) 1 Layer PALF-poly Mat (c) 2 Layer PALF-poly Mat (d) 3 Layer PALF-poly Mat (e) Average for each sample

3.5 Sound Reduction Index

Figure 4.9 below compares the SRI tests done on the control and PALF-poly samples to check for sound insulation properties. The SRI for the control samples was at: Sample 1 showed a constant value of 27.56 dB at 0.5 m, 21.56 dB at 1.0 m, and 22.76 dB at 1.5 m; Sample 2 showed lesser values with 13.96 dB at 0.5 m, 15.81 dB at 1.0 m, and 17.71 dB at 1.5 m; while Sample 3 showed an SRI value between Samples 1 and 2 with 16.81 dB at 0.5 m, 17.21 dB at 1.0 m, and 14.81 dB at 1.5 m. The highest values were at 1.5 m in the case of 1 Layer PALF-poly variety: Sample 1 recorded 29.76 dB, Sample 2 recorded 32.21 dB, and Sample 3 recorded 30.71 dB. Two Layer PALF-poly variety showed Sample 1 peaking at 1.0 m with 25.96 dB, and Sample 2 showed a fall as the distance increased, whereas Sample 3 peaked at 1.0 m, showing 23.61 dB. In the case of 3 Layer PALF-poly, it was quite consistent as Sample 1 recorded 17.26 dB at 1.5 m, Sample 2 had steadied values, that is, 19.16 dB at 0.5 m, 1.0 m, and 20.36 dB at 1.5 m, and Sample 3 reflected gradual increase, that is, 20.51 dB at 0.5 m, 19.51 dB at 1.0 m, and 22.1 dB at 1.5 m. Fig. Where Figure 12 illustrates the SRI graph for all configurations and average values at 0.5 m, 1.0 m, and 1.5 m distances.



(a) **(b)** **(c)** **(d)** **(e)**

Fig. 12: Sound Reduction Index (a) Control Sample (b) 1 Layer PALF-poly Mat (c) 2 Layer PALF-poly Mat (d) 3 Layer PALF-poly Mat (e) Average for each sample

3.6 Relationship Between Sound Acoustic vs Compressive Strength

The 2-layer PALF-poly composite gives the optimum balance of sound reduction against compressive strength, having an average SRI of 20.17 dB and compressive strength of 34.5 MPa, thus being suitable for applications with acoustic performance and structural integrity. The control sample, while giving a higher compressive strength of 29.69 MPa, had inferior sound insulation of 18.69 dB, whereas the 1-layer PALF-poly had lower values for SRI of 16.51 dB and compressive strength of 26.46 MPa. The 3-layer PALF-poly showed a reduction in compressive strength to 33.99 MPa and a reduction in sound reduction to 18.94 dB, which further solidifies the 2-layer configuration as the most optimal choice, as represented in Figure 13.

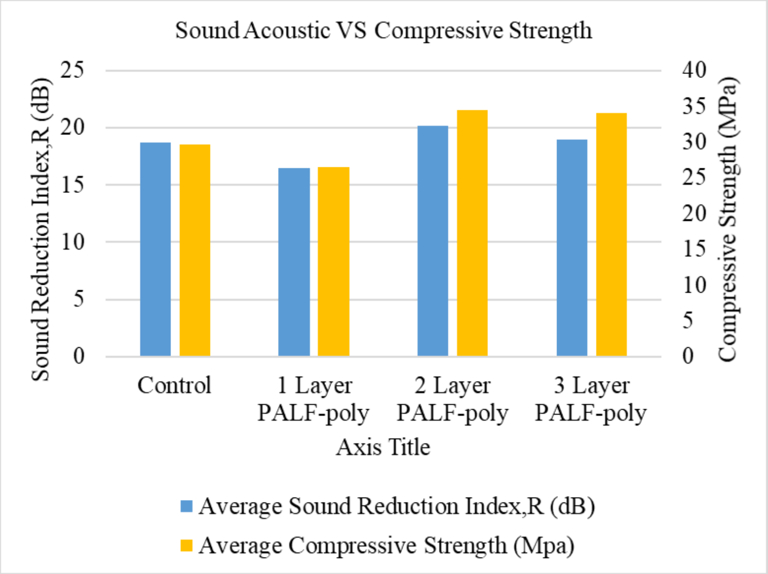


Fig. 13: Sound Acoustic VS Compressive Strength

4. Conclusion

This study focused on the physical and mechanical characterization of HPCs produced using epoxy resin with PALF-poly fibre mats. SEM showed that PALF presented a rough surface, polyester presented smooth and elongated structures and epoxy had a transparent and smooth surface. XRD has revealed some essential peaks at 21.89° for PALF, 19.54° for polyester, and 18.83° for epoxy. At the same time, FTIR confirmed the presence of hydroxyl and carbonyl functional groups in PALF, ester groups in polyester, and peaks from curing in epoxy. These have provided the highest compressive strength and sound reduction of 34.50 MPa and 20.17 dB, respectively, obtained in mechanical testing for the 2-layer PALF-poly composite over the control samples, 1-layer, and 3-layer samples. Results show that the 2-layer PALF-poly composite is superior and promising for engineering applications.

Acknowledgement

The authors would like to extend their most significant appreciation to everyone who contributed to this work. Special thanks to the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, for the continuous support.

References

[1] Elfaleh, I., Abbassi, F., Habibi, M., Ahmad, F., Guedri, M., Nasri, M., & Garnier, C. (2023). A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. *Results in Engineering*, *19*(April). https://doi.org/10.1016/j.rineng.2023.101271

[2] Yumnam, G., Gyanendra, Y., & Singh, C. I. (2024). A systematic bibliometric review of the global research dynamics of United Nations Sustainable Development Goals 2030. *Sustainable Futures*, *7*(October 2023). https://doi.org/10.1016/j.sftr.2024.100192

[3] Swain, P. K., Rout, A. kumar, Singh, J. K., Sahoo, D., & Mishra, S. K. (2024b). Development and analysis of Fe-doped ZnO nanoparticle-infused sisal fiber reinforced hybrid polymer composites for high-performance sound absorption and thermal insulation applications. *Industrial Crops and Products*, *222*(P3), 119763. https://doi.org/10.1016/j.indcrop.2024.119763

[4] Todkar, S. S., & Patil, S. A. (2019). Review on mechanical properties evaluation of pineapple leaf fibre (PALF) reinforced polymer composites. *Composites Part B: Engineering*, *174*(May). https://doi.org/10.1016/j.compositesb.2019.106927

[5] Velmurugan, G., Kumar, G., Singh Chohan, J., Nithya Sree, S., Akash, J., & Deepthi, J. B. (2024). Experimental investigation of mechanical and erosion properties of twill E-glass/sisal fiber reinforced hybrid polymer composite. *Materials Today: Proceedings*, *February*, 1–7. https://doi.org/10.1016/j.matpr.2024.03.032

[6] Swain, P. K., Rout, A. kumar, Singh, J. K., Sahoo, D., & Mishra, S. K. (2024a). Development and analysis of Fe-doped ZnO nanoparticle-infused sisal fiber reinforced hybrid polymer composites for high-performance sound absorption and thermal insulation applications. *Industrial Crops and Products*, *222*(September). https://doi.org/10.1016/j.indcrop.2024.119763

[7] Shaik, M. S., & Sankara Subramanian, H. (2023). An experimental study on low-velocity impact response of abaca/epoxy and abaca/rubber hybrid composites: A comparative study. *Materials Today: Proceedings*, *xxxx*. https://doi.org/10.1016/j.matpr.2023.04.335

[8] Hasanuddin, I., Mawardi, I., Nurdin, N., & Jaya, R. P. (2023). Evaluation of properties of hybrid laminated composites with different fiber layers based on Coir/Al2O3 reinforced composites for structural application. *Results in Engineering*, *17*(January). https://doi.org/10.1016/j.rineng.2023.100948

[9] Siddiqui, V. U., Sapuan, S. M., & Jamal, T. (2023). Mechanical, Morphological, and Fire Behaviors of Sugar Palm/ Glass Fiber Reinforced Epoxy Hybrid Composites. *Pertanika Journal of Science and Technology*, *31*(S1), 139–155. https://doi.org/10.47836/pjst.31.S1.08

[10] Composites, R. E. (2018). *Thermal and Mechanical Properties of Bamboo Fiber Reinforced Epoxy Composites*. https://doi.org/10.3390/polym10060608

[11] Indra Reddy, M., Prasad Varma, U. R., Ajit Kumar, I., Manikanth, V., & Kumar Raju, P. V. (2018). Comparative Evaluation on Mechanical Properties of Jute, Pineapple leaf fiber and Glass fiber Reinforced Composites with Polyester and Epoxy Resin Matrices. *Materials Today: Proceedings*, *5*(2), 5649–5654. https://doi.org/10.1016/j.matpr.2017.12.158

[12] Zhao, D., Mao, K., Yang, Y., & Hamada, H. (2017). Flexural behavior evaluation of needle-punched glass/jute hybrid mat reinforced polymer composites. *Procedia Engineering*, *200*, 10–17. https://doi.org/10.1016/j.proeng.2017.07.003

[13] Deeban, B., Maniraj, J., & Ramesh, M. (2023). Experimental investigation of properties and aging behavior of pineapple and sisal leaf hybrid fiber-reinforced polymer composites. *E-Polymers*, *23*(1). https://doi.org/10.1515/epoly-2022-8104