Characterization of Void content, tensile strength, and chemical resistance in Hybrid Polymer Composites Reinforced with Oil Palm and Jute Fibers

Dr. Kiran Angra[1], Dinesh Kumar[2], Dr. Surjit Angra[3]

[1]Principal, MDSD College, Ambala City, Haryana, India
[2]Research Scholar, Department of Mechanical Engineering, NIT Kurukshetra, Haryana, India
[3]Professor, Department of Mechanical Engineering, NIT Kurukshetra, Haryana, India

Abstract

Oil palm empty fruit bunches (EFBS) and jute fibres were used as outer and inner layers to create a tri-layer hybrid composite. Oil palm EFBS-jute composites were tested for void content, tensile strength, and chemical resistance. The research examined the 4:1 oil palm EFBS-jute weight ratio. Optimized fibre loading and stacking patterns were tested. The Jute-fibre/EFBS/Jute-fibre hybrid composites had the maximum tensile strength of 28.72 MPa and a lower void content of 3.18%. Both hybrid composites have superior chemical resistance compared to pure fibres. However, Jute-fiber/EFBS/Jute-fiber hybrid composites outperform EFBS/Jute-fiber/EFBS hybrid composites, showing an improvement of 5% to 30% under various chemical conditions.

Keywords: Polymer composites, Hybrid composites, Oil palm fibres, Jute fibres, Mechanical characterization

1. Introduction

Polymer composites find extensive applications in a diverse range of products, including golf clubs, jet skis, tennis rackets, aerospace components (aircraft, missiles, and spacecraft), marine equipment, transportation systems, chemical apparatus, electrical and electronics devices, and storage tanks [1]. Composites are complicated solid materials made by combining two or more components for improved properties. Lightweight, strong-to-weight, and stiff polymer composites have replaced metals and wood as preferred materials [2]. Fibres provide strength and rigidity, while the plastic matrix acts as an adhesive to make structurally sound components. Natural fibre reinforcements for thermoplastics and thermosets are becoming increasingly common [3]–[5].

Table 1: Properties of different fibres

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation (%)
Jute Fibre	1.2	395-771	26.3	1.4-1.9
EFBS Fibre	0.6-1.52	246	2-8	7-15

Natural fibres from renewable resources are cheaper to manufacture, lighter, stronger, stiffer, safer, and biodegradable. Hybrid composites combine many fibres in one matrix [6]. This method increases the flexibility of fibre-reinforced composite materials by giving them properties unrelated to their components. In terms of both physical and mechanical properties, jute demonstrates superior performance compared to other natural fibres [7]. Table 1 presents the different properties of used fibres. Padma Priya and colleagues studied epoxy laminates enhanced using discarded silk fabric for mechanical and chemical resistance. They also examined waste silk fabric/epoxy composites' impact strength, tensile strength, density, and weight reduction [8]. Sidhesh Kumar and colleagues investigated the chemical durability of unsaturated polyester hybrid composites enhanced with kapok-glass fibres and kapok-sisal fabric fibres [9]. They examined the compressive, chemical resistance, and thermal properties of polyester composites with kapok/sisal fabrics. The current study analyses epoxy-based matrix tri-layer EFBS/Jute/EFBS hybrid fibre composite and Jute/EFBS/Jute hybrid fibre composite. The examination examines void content, tensile strength, and chemical resistance under various stacking patterns. Scanning electron microscopy examines composite fracture surfaces to study reinforcing fibre-matrix interaction.

2. Materials and methods

2.1. Materials

EFBS and jute fibre mats (as shown in Figure 1) were purchased from Eco-fibre Technology Sdn. Bhd. in Malaysia and Indarsen Shamlal Pvt. Ltd. (Jute House since 1948) in Kolkata, India. Zarm Scientific & Supplies Sdn. Bhd. supplied epoxy resin, mainly DGEBA, and epoxy hardener A062. Aldrich provided benzyl alcohol for dilution.

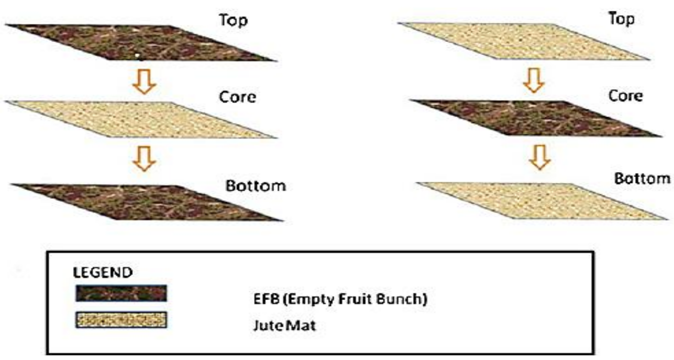

Figure 1: Layers of Matrix and reinforcement material

2.2. Fabrication Route

The composites were produced from oil palm EFBS and jute-chopped fibre matting as shown in Figure 2. A 304 mm by 203 mm stainless-steel mould was employed with a thin silicone oil solution coating as a release agent. The composite was created by blending epoxy resin and polyamide with the addition of benzyl alcohol. The mixture was mechanically stirred for 15 minutes. In the mould, EFBS and jute fibre mats were layered and soaked with epoxy resin. Figure 2 shows several steps involved in fabrication process of polymer composites. A control sample with an ordered epoxy matrix without fillers and composites with EFBS and jute fibres was made. ASTM criteria were followed to obtain composite samples for void content, tensile strength, and chemical resistance [10].

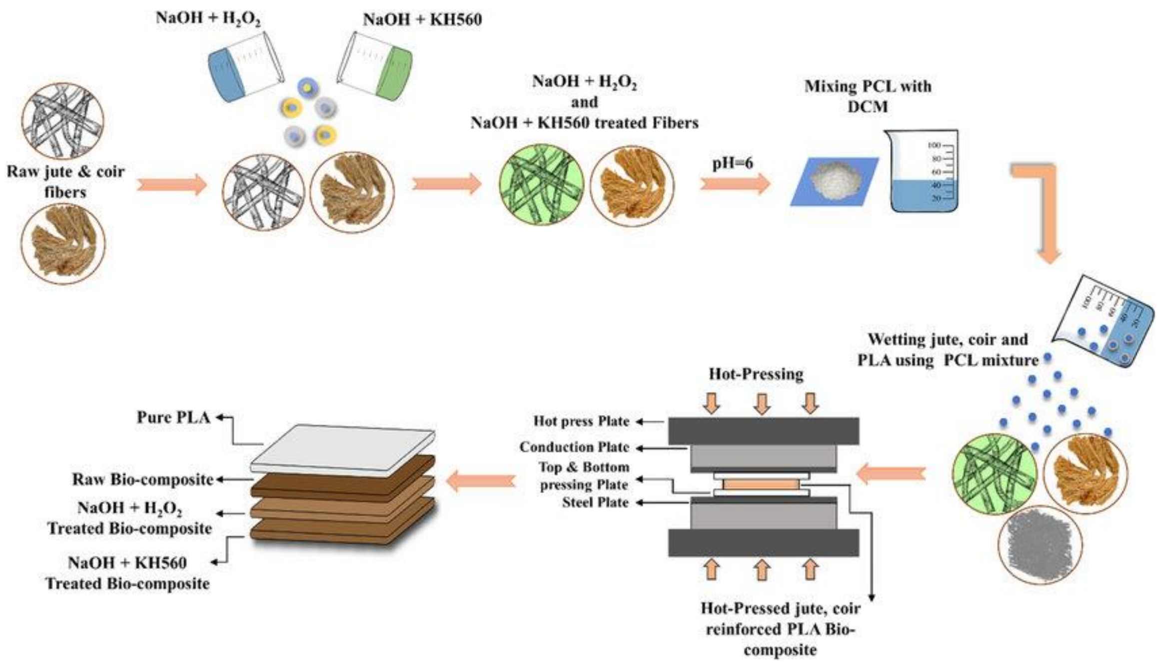

Figure 2: Graphical representation for fabrication of polymer composites

3. Composites Characterization

3.1. Void Content

Composite void content was assessed using ASTM D 2734-94 [25]. Equation (2) factors in composites' theoretical and experimental densities to calculate void content:

$$\text{Void Content } (\%) = \left(1 - \frac{\text{Experimental Density}}{\text{Theoretical Density}}\right) \times 100$$

This method helped calculate composite material air gap ratios. The predicted and experimental densities indicated the composite structure's void content, with a greater percentage indicating more voids.

3.2. Tensile Strength

The capacity of a substance to resist tugging or stretching without breaking. Tensile properties of both the matrix and composites, reinforced with EFBS/Jute/EFBS hybrid composite and Jute/EFBS/Jute fibres hybrid composite, were evaluated using an INSTRON 5582 Universal Testing Machine. The testing procedures adhered to the ASTM D 3039 standard [11]. Each circumstance was examined with five specimens, and the average findings were reported. This method helped analyse the materials' tensile strength, modulus, and other properties, revealing the composite's stress performance.

3.3. Chemical resistance

Hybrid composites, reinforced with EFBS/Jute/EFBS hybrid composite and Jute/EFBS/Jute fibres hybrid composite and utilizing epoxy resin, underwent chemical resistance testing according to ASTM D 543-87 [12]. The study studied the effects of solvents like toluene, benzene, and carbon tetrachloride, acids like nitric acid and hydrochloric acid, and alkalies like NaOH, Na_2CO_3, and NH_4OH on matrix and hybrid composites [13], [14].

$$\text{Percentage Weight Loss/Gain} = \left(\frac{\text{Final Weight} - \text{Initial Weight}}{\text{Initial Weight}}\right) \times 100$$

Five pre-weighed samples were in each chemical reagent for 24 hours. The samples were then extracted, washed with distilled water, and dried by pressing both sides with filter paper at room temperature. Desiccated specimens were remeasured and the % weight change was determined. By measuring the % weight change after exposure to several chemical reagents, this method assessed composite materials' durability.

4. Results and discussions

4.1. Void Content

Composites' mechanical and physical properties are affected by voids, reducing performance. In the process of incorporating fibres into the matrix or producing fibre-reinforced composites, these empty spaces have the potential to harbour air or other volatile substances. If the matrix fails to extract all the air from the woven or chopped fibres during impregnation, voids commonly form. Table 2 shows composite samples with different stacking patterns' empty content percentages. Oil palm EFBS fibre composites contained 8.6% voids compared to 2.6% for jute fibre composites. The mismatch between the epoxy resin and the oil palm EFBS fibres may be traced to the fact that the two materials are incompatible with one another. Previous research conducted by a variety of researchers has shown that the creation of voids may occur when the matrix does not adequately moisten the fibres [15]–[17]. The porous nature and loose arrangement of oil palm EFBS fibres lead to the extrusion of resin from the mat during the moulding process. In the case of Jute/EFBS/Jute hybrid composites, positioning the EFBS fibre layer between two jute fibre skins reduces the exposure of oil palm fibres. The denser and more compatible nature of jute fibre mats with epoxy resin contributes to Jute-fibre/EFBS/Jute-fibre hybrid composites having fewer voids compared to EFBS/Jute/EFBS hybrid composites. Layer layout reduces vacant space and strengthens composite structure.

Table 2: Void (%) of different fabricated composites

S.No.	Composites	Void (%)
1	Pure Jute	2.65
2	Pure EFBS	8.52
3	Jute-fibre/EFBS/Jute-fibre	3.18
4	EFBS/Jute/EFBS	4.86

4.2. Tensile Strength

Park and Jang found that hybrid laminated composites' mechanical properties depended on component arrangement. Research conducted by various researchers underscores the influence of hybrid composite fibre arrangement on tensile strength and modulus [18]–[20]. While studies on synthetic-natural fibre composites have been extensive for environmental considerations, hybrid composites with natural fibres are relatively recent. Research on the tensile strengths of hybrid composites made of sisal and another natural fibre, such as silk or banana, shows that this combination improves the mechanical qualities of the final product. Hybrid composites that use various fibres allow for one kind of fibre to substitute for the limits of another type of fibre, reaching an appropriate equilibrium between cost and performance via the design of the material.

Table 3: Tensile properties of different fabricated composites

S.No.	Composites	Tensile Strength (MPa)	Modulus of Elasticity (GPa)
1	Pure Jute	47.54	3.86
2	Pure EFBS	23.87	2.21
3	Epoxy	19.83	1.95
4	Jute-fibre/EFBS/Jute-fibre	28.49	2.48
5	EFBS/Jute-fibre/EFBS	26.25	2.36

Table 3 illustrates the tensile properties of EFBS/Jute-fiber/EFBS hybrid composites and Jute-fibre/EFBS/Jute-fibre hybrid composites, revealing that employing jute fibre as the matrix and oil palm EFBS fibre as the reinforcement enhances tensile properties of the fabricated composites. This supports the assumption that the skin, which supports the load in tensile measurements, should be strong. Due to the outer layer's low-strength EFBS fibre composite, the EFBS/Jute/EFBS hybrid composite has a lower tensile strength. Satish et al., Afzail et. al., and Omrani et. al. obtained comparable findings with sisal-banana composites [21]–[23]. Tensile strength data demonstrate that the pure jute fibre composite has the highest strength (45.55 MPa), indicating a strong bond between the fibre and epoxy matrix. However, the pure EFBS composite has a much lower tensile strength of 22.61 MPa, suggesting extensive porosity. Porosity in oil palm EFBS fibre composites may be due to air entrapment [24]. The fiber-matrix interface, which affects mechanical properties, contributes to the tensile strength differences between the two pure composites.

4.3. Chemical resistance

In evaluating their chemical resistance, hybrid composites underwent exposure to various chemicals, aiming to assess their suitability for chemical-resistant applications. Table 4 outlines the weight changes, either in loss or gain, observed in epoxy, pure EFBS composite, pure jute, EFBS/Jute/EFBS hybrid composites, and Jute-fibre/EFBS/Jute-fibre reinforced hybrid composites when subjected to various pollutants.

Table 4: Chemical resistance of different composites under various chemicals

Chemical	Pure Jute	Pure EFBS	Epoxy	Jute-fibre/EFBS/Jute-fibre	EFBS/Jute/EFBS
CCl_4	0.3254	5.0954	0.368	3.6978	1.8243
HCl	0.1254	15.987	1.926	10.124	7.5897
NaOH	0.0874	15.784	5.264	20.109	15.7842
NH_4OH	0.3054	20.987	4.026	13.398	3.9654
Na_2CO_3	0.1987	10.067	0.887	5.267	3.8214
Benzene	0.4158	8.2654	0.492	3.4658	3.3457

The table provides insights into the chemical resistance characteristics of 100% EFBS reinforced with jute fibre composites. The results indicate an overall weight gain in all cases, suggesting that the composites did not experience weight loss and, consequently, did not undergo significant erosion. Notably, when oil palm EFBS fibre was utilized as the matrix material and jute fibre as reinforcement, the fabricated composites exhibited higher weight. This tendency was not always followed, indicating it is not universal. OH, groups in oil palm EFBS fibre cellulose may have increased hydrophilicity in certain circumstances. Compared to pure systems, tri-layered hybrid composites have better chemical resistance. This shows that adding jute fibre to polymers boosts chemical resistance. The matrix and composites were superior chemically resistant to all studied substances, indicating their potential usage in chemical-resistant applications.

5. Conclusions

In conclusion, the study investigated epoxy-based tri-layer composites reinforced with EFBS/Jute/EFBS hybrid composite and Jute/EFBS/Jute hybrid composite. The key findings and conclusions drawn from the research are as follows:

1. The use of natural fibres, such as jute and oil palm EFBS, in the composites aligns with environmental concerns, offering a sustainable alternative to synthetic fibres.
2. Hybridization with jute fibres significantly reduced the void content in the composites compared to Pure EFBS and EFBS/Jute/EFBS hybrid composites. The densely packed and epoxy resin-compatible nature of jute fibre mats contributed to this reduction.
3. Hybrid composite also demonstrated a lower void content of 3.18, signifying improved structural integrity and denser packing compared to EFBS/Jute-fiber/EFBS hybrid composites
4. The hybrid composites exhibited enhanced tensile strength and modulus, with the arrangement of jute fibres as the matrix material and oil palm EFBS fibres as the reinforcement.
5. Jute-fibre/EFBS/Jute-fibre hybrid composites exhibited the highest tensile strength at 28.72 MPa, indicating superior mechanical performance.
6. The hybrid composites demonstrated strong resistance to a variety of chemicals, including acids, alkalis, solvents, and pollutants. This indicates their potential for use in chemical-resistant applications.
7. Jute-fiber/EFBS/Jute-fiber hybrid composites outperformed EFBS/Jute-fiber/EFBS hybrid composites across different chemical conditions, showing an improvement ranging from 5% to 30%.
8. The study underscores the potential of these hybrid composites for applications requiring chemical resistance and superior mechanical properties.
9. The findings open avenues for further research in optimizing the layering patterns and exploring additional properties of hybrid composites for diverse applications

References

1. C. Saravanan *et al.*, ‘Investigation on the mechanical, tribological, morphological and machinability behavior of stir-casted Al/SiC/Mo reinforced MMCs’, *Materials Today: Proceedings*, vol. 21, no. xxxx, pp. 1–10, 2020, doi: 10.1016/j.ceramint.2020.01.192.
2. M. P. Muthuraj and K. Nithyapriya, ‘Experimental studies on multicellular GFRP bridge deck panels under static and fatigue loading’, *Sadhana*, vol. 42, no. 12, pp. 2171–2181, 2017, doi: 10.1007/s12046-017-0747-0.
3. T. S. Sadagoapan and P. Ravindran, ‘A continuum model for predicting strain evolution in carbon fiber- reinforced composites subjected to cyclic loading’, *Sādhanā*, vol. 0123456789, 2022, doi: 10.1007/s12046-021-01728-8.

4. P. Phani Prasanthi, K. Sivaji babu, and A. Eswar Kumar, 'Waviness effect of fiber on buckling behavior of sisal/carbon nanotube reinforced composites using experimental finite element method', *International Journal of Engineering, Transactions B: Applications*, vol. 34, no. 12, pp. 2617–2623, 2021, doi: 10.5829/IJE.2021.34.12C.06.
5. Q. B. Nguyen, M. L. Sharon Nai, A. S. Nguyen, S. Seetharaman, E. W. Wai Leong, and M. Gupta, 'Synthesis and properties of light weight magnesium-cenosphere composite', *Materials Science and Technology (United Kingdom)*, vol. 32, no. 9, pp. 923–929, 2016, doi: 10.1080/02670836.2015.1104017.
6. W. Xu, S. Zhang, W. Liu, and Y. Yu, 'Highly tough 3D woven composite materials: Fracture characterization and toughening mechanisms', *Theoretical and Applied Fracture Mechanics*, vol. 124, no. December 2022, pp. 29–35, 2023, doi: 10.1016/j.tafmec.2022.103734.
7. S. Singh and S. Angra, 'Experimental evaluation of hygrothermal degradation of stainless steel fibre metal laminate', *Engineering Science and Technology, an International Journal*, vol. 21, no. 1, pp. 170–179, 2018, doi: 10.1016/j.jestch.2018.01.002.
8. P. C. Gope, 'Maximum tangential stress coupled with probabilistic aspect of fracture toughness of hybrid bio-composite', *Engineering Science and Technology, an International Journal*, vol. 21, no. 2, pp. 201–214, 2018, doi: 10.1016/j.jestch.2018.03.008.
9. N. M. Siddesh Kumar, M. Sadashiva, J. Monica, and S. Praveen Kumar, 'Investigation on Corrosion Behaviour of Hybrid Aluminium Metal Matrix Composite Welded by Friction Stir Welding', *Materials Today: Proceedings*, vol. 52, pp. 2339–2344, 2021, doi: 10.1016/j.matpr.2022.01.362.
10. S. P. Venkatesan, G. Muthuswamy, R. Shyam Sundar, S. Ganesan, and J. Hemanandh, 'Investigation of mechanical properties of aluminum metal matrix composites with nanomaterial reinforcement', *Materials Today: Proceedings*, vol. 62, pp. 572–582, 2022, doi: 10.1016/j.matpr.2022.03.594.
11. S. Singh and S. Angra, 'Flexural and Impact Properties of Stainless Steel based Glass Fibre Reinforced Fibre Metal Laminate under Hygrothermal Conditioning', vol. 31, no. 1, pp. 164–172, 2018.
12. S. Kashyap, H. Tripathi, and N. Kumar, 'MECHANICAL PROPERTIES OF MARBLE DUST REINFORCED ALUMINUM MATRIX STRUCTURAL COMPOSITES FABRICATED', vol. 48, no. 2, pp. 282–288, 2022, doi: 10.18149/MPM.4822022.
13. M. Mobin, R. Aslam, R. Salim, and S. Kaya, 'An investigation on the synthesis, characterization and anti-corrosion properties of choline based ionic liquids as novel and environmentally friendly inhibitors for mild steel corrosion in 5% HCl', *Journal of Colloid and Interface Science*, vol. 620, pp. 293–312, 2022, doi: 10.1016/j.jcis.2022.04.036.
14. E. O. Opare, E. Struhs, and A. Mirkouei, 'A comparative state-of-technology review and future directions for rare earth element separation', *Renewable and Sustainable Energy Reviews*, vol. 143, no. February, p. 110917, 2021, doi: 10.1016/j.rser.2021.110917.
15. S. Stankovich *et al.*, 'Graphene-based composite materials', *Nature*, vol. 442, no. 7100, pp. 282–286, 2006, doi: 10.1038/nature04969.
16. B. Radovan, F. Mária, K. Peter, and J. Füzer, 'Preparation and properties of Fe-based composite materials', *Proceedings of the World Powder Metallurgy Congress and Exhibition, World PM 2010*, vol. 5, no. August 2017, 2010.
17. A. H. Abdalsalam *et al.*, 'Investigation of gamma ray attenuation features of bismuth oxide nano powder reinforced high-density polyethylene matrix composites', *Radiation Physics and Chemistry*, vol. 168, p. 108537, 2020, doi: 10.1016/j.radphyschem.2019.108537.

18. A. T. Abbas, A. J. Al-obaidi, and S. J. Ahmed, 'SYNTHESIS AND STUDY OF THE MECHANICAL PROPERTIES OF BIODEGRADABLE POLYVINYL ALCOHOL / EGGSHELL COMPOSITES', vol. 16, no. 4, pp. 3084–3093, 2021.
19. A. Kubit, 'the Effect of Adhesive Type on Strength of Inter-Layer Joints in Fiber Metal Laminate Composites', *Composites Theory and Practice*, vol. 17, no. 3, pp. 162–168, 2017.
20. R. V. S. Manivannan and P. S. V Vijayan, 'The Investigation on Newly Developed of Hydrophobic Coating on Cast AZ91D Magnesium Alloy Under 3 . 5 wt % NaCl Solutions', *Journal of Inorganic and Organometallic Polymers and Materials*, vol. 32, no. 4, pp. 1246–1258, 2022, doi: 10.1007/s10904-021-02174-z.
21. S. Sathish, K. Kumaresan, L. Prabhu, and N. Vigneshkumar, 'Experimental investigation on volume fraction of mechanical and physical properties of flax and bamboo fibers reinforced hybrid epoxy composites', *Polymers and Polymer Composites*, vol. 25, no. 3, pp. 229–236, 2017, doi: 10.1177/096739111702500309.
22. M. Afzali and V. Asghari, 'Analyzing mechanical behavior of abs-sio2 polymer-based nanocomposite based on anova method', *Composites Theory and Practice*, vol. 2021, no. 3, pp. 61–69, 2021.
23. E. Omrani, P. L. Menezes, and P. K. Rohatgi, 'State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world', *Engineering Science and Technology, an International Journal*, vol. 19, no. 2, pp. 717–736, 2016, doi: 10.1016/j.jestch.2015.10.007.
24. F. O. Edoziuno, C. C. Nwaeju, A. A. Adediran, B. U. Odoni, and V. R. Arun Prakash, 'Mechanical and microstructural characteristics of Aluminium 6063 Alloy/Palm Kernel shell composites for lightweight applications', *Scientific African*, vol. 12, p. e00781, 2021, doi: 10.1016/j.sciaf.2021.e00781.