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Research Article

Evaluation of Thermal Adsorption and Mechanical Behaviour of Intralaminar Jute/Sisal/E-Glass Fibre-Bonded Epoxy Hybrid Composite as an Insulator

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A thermal gravimetric analyzer analyzed the thermal adsorption properties of developed composites with the temperature range of 28°C–650°C at a 20°C/min constant heat flow rate. The epoxy hybrid composites were synthesized using natural jute/sisal fibre hybridized with the addition of synthetic E-glass fibres at 0-degree, 0/90-degree, and intralaminar orientations through the wet filament-winding process. The effects of orientations on tensile, flexural, and impact strengths of epoxy hybrid composites were studied using ASTM D3039, D790, and D6110. The evaluated results were compared, and the epoxy hybrid composite containing intralaminar orientations found better thermal stability with reduced weight loss at 650°C. Similarly, the test result for mechanical studies of the hybrid composite showed superior tensile, flexural, and impact strengths. The epoxy hybrid composite with intralaminar orientation was found to have a maximum tensile, impact, and flexural strength of 61.91 MPa, 770.61 J/m, and 83.90 MPa, respectively.

1. Introduction

The polymer matrix hybrid composites are prepared with natural and synthetic fibre grouping, facilitating good toughness, high strength, better thermal stability, and high corrosion resistance compared to conventional plastic materials. The interfacial bonding strength between the fibre and matrix mainly depends on the enhancement of the composite. More than one reinforcement fibre makes an effective hybrid composite with superior performance applied to various engineering applications [1–6]. The hybrid composites are cheaply prepared with natural and synthetic fibres [7, 8]. The hybridization composite can achieve the desired specific properties with the appropriate selection of natural and synthetic fibres. The applications of hybrid composites have increased in recent years in the fields of structural engineering, construction, sports, and defence [9–15].

Natural fibres are the best alternative for conventional artificial fabric fibres bonded with a poly material that is high strength, nontoxic, renewable, and eco-friendly [16, 17]. Moreover, the ecological behaviour of natural fibres facilitates low density and better damping capability in combination with glass fibres [18]. The epoxy composite was hybridized with jute/sisal fibre via the conventional technique to find the composite's increased tensile strength which had an increase of 77% when compared to the nonreinforced jute composite [19]. The water absorption and mechanical performance of the sisal/stalk fibre hybrid composite were evaluated based on ASTM standards. The results found that the tensile and flexural strengths of the composite were enhanced by 20% and 49.5%, respectively. The effect of water absorption was limited by adding sisal fibre [20]. The hybridization effect of the hybrid composite was enhanced using different jute/banana fibres that showed high flexural, tensile, and impact strengths and good thermal stability at 50 wt% of jute/epoxy [21].

The polymer composite was developed with jute and glass fibres via the conventional technique. The results showed that jute and glass fibre combinations showed better mechanical characteristics and good thermal behaviour [22]. The different volumes (30–50) of a banana/pineapple/glass fibre-reinforced hybrid composite were studied for their mechanical and thermal characteristics. The composite composed of 40 vol% showed better mechanical performance, and TGA analysis revealed that the composite has optimum thermal adsorption compared to others [23]. The effect of sisal fibre on jute-reinforced thermal and mechanical properties of the epoxy hybrid composite was evaluated. The experimental results showed that the presence of the sisal fibre in the epoxy composite results in superior thermal properties like high-storage modulus and limited weight loss. The mechanical strength is higher than in the ordinary jute fibre-reinforced epoxy composites [24]. The polypropylene composite was prepared with glass/sisal fibre, and its thermal characteristics were studied via TGA. The decomposition ratio at higher temperatures limits the thermal adsorption properties of the polypropylene composite. This is due to the incorporation of the glass fibre as part of hybridization with the composite [25]. Researchers synthesized the hemp fibre-bonded polymer matrix composite via the conventional technique. Hemp fibre in the polymer matrix resulted in good thermal properties compared to the polymer matrix composite without hemp fibre [26].

Similarly, other researchers reported that the thermal conductivity of the polymer matrix composite was enhanced by the presence of hemp fibre [27]. Moreover, the E-glass fibre-reinforced epoxy composite showed better thermal behaviour and enhanced thermal stability between 25°C and 1000°C [28]. The present research investigates enhancing the thermal adsorption and mechanical properties of epoxy hybrid composites bonded with different orientations of natural jute/sisal/E-Glass fibres. The impacts of the experimental results of different orientations on thermal adsorption and mechanical performance are compared. Finally, the enhanced value of the composite sample is recommended for insulator applications.

2. Materials and Methods

Epoxy resin and hardener are chosen as the base polymer resin matrix. The continuous natural jute/sisal is considered the reinforcement fibre, and synthetic E-glass fibre is the choice for hybridizing the epoxy/jut/sisal fibre composite. However, natural jute/sisal fibres have higher stiffness, low density, and good thermal properties [21, 22]. The sisal fibre constitutions in the epoxy composite hybridized with E-glass fibre result in increased mechanical and thermal adsorption characteristics [5, 9, 16]. The physical, mechanical, and thermal properties of jute, sisal, and E-glass fibres are mentioned in Table 1.

Table 1: Physical, mechanical, and thermal properties of jute/sisal/ and E-glass fibre.

Fibre	Density g/cc	Tensile strength MPa	Elastic modulus GPa	Thermal conductivity W/mK
Jute	1.5	390-770	15	427.3
Sisal	1.29	570-710	22	0.205
E-glass	2.54	3400	72	0.03

2.1. Fabrication of Jute/Sisal/E-Glass Fibre-Bonded Epoxy Hybrid Composites. Figures 1(a)–1(c) illustrate the fabrication setup with a fibre mandrel wrap, epoxy resin pool, and filament-winding robot arm. The continuous jute/sisal/ E-glass fibres were held separately using the fibre mandrel wrap configured with a stepper motor. Similarly, the 60 : 40 volume fractions of the epoxy resin and hardness were mixed uniformly in the wet filament resin pool container. The individually wrapped continuous jute, sisal, and E-glass fibres were dipped into an epoxy resin pool. The tipped continuous fibres have been winded with the help of a robot. Based on the specified orientations, epoxy hybrid composites were developed.

Finally, the prepared epoxy composite was naturally dried at ambient temperature. ASTM test standards shaped the synthesized composites. All the fibres are formed via a shuttle and part filament-winding axle as per (a) zero orientation, (b) 0- and 90-degree cross-orientation, and (c) intralaminar model block diagram as shown in Figure 2.

2.2. Evaluations of Developed Composite Samples. The epoxy hybrid composite was contained in a thermal gravimetric analyzer that experimentally measured the jute/sisal/E-glass fibre's thermal adsorption and heat deflection properties at a constant heat flow rate of 20°C/min. The developed composite samples were evaluated based on ASTM standards. The tensile and flexural strengths of the composite were evaluated via an FIE-made UTM machine with a cross-slide speed of 5 mm/min according to ASTM D3039 and ASTM D790. The IT-made Charpy impact tester measured the impact toughness of the composite based on the ASTM D6110 standard.

3. Results and Discussions

3.1. Thermal Characteristics Study

3.1.1. Thermal Adsorption Characteristics Study. The thermal adsorption performance of hybrid composites is studied with different fabric orientations, following Figure 2. The composite was a 5 mm × 5 mm sample and kept in the thermal gravimetric analyzer apparatus. During the thermal gravimetric analysis, the temperature is varied from 28°C to 650°C at a 20°C/min constant heat flow rate. Figure 3(a) indicates the thermal adsorption-mass loss curve of a hybrid composite with different laminates. The 0-degree orientations

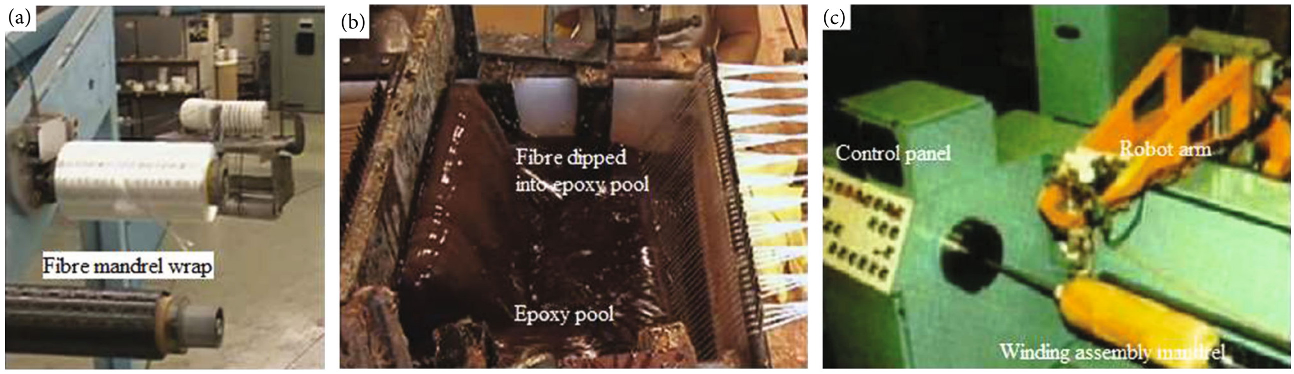

Figure 1: Actual fabrication setup of wet winding machine. (a) Fibres are placed in roving roller, (b) resin bath, and (c) filament-winding robot arm with a fabric mat.

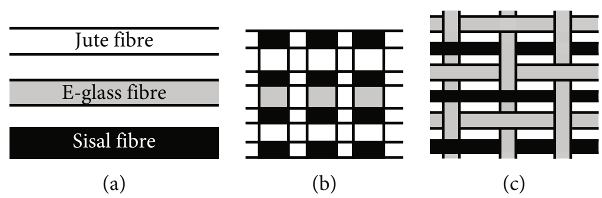

Figure 2: Different arrangements of fibre in epoxy composite: (a) zero orientation, (b) 0- and 90-degree cross-orientation, and (c) intralaminar.

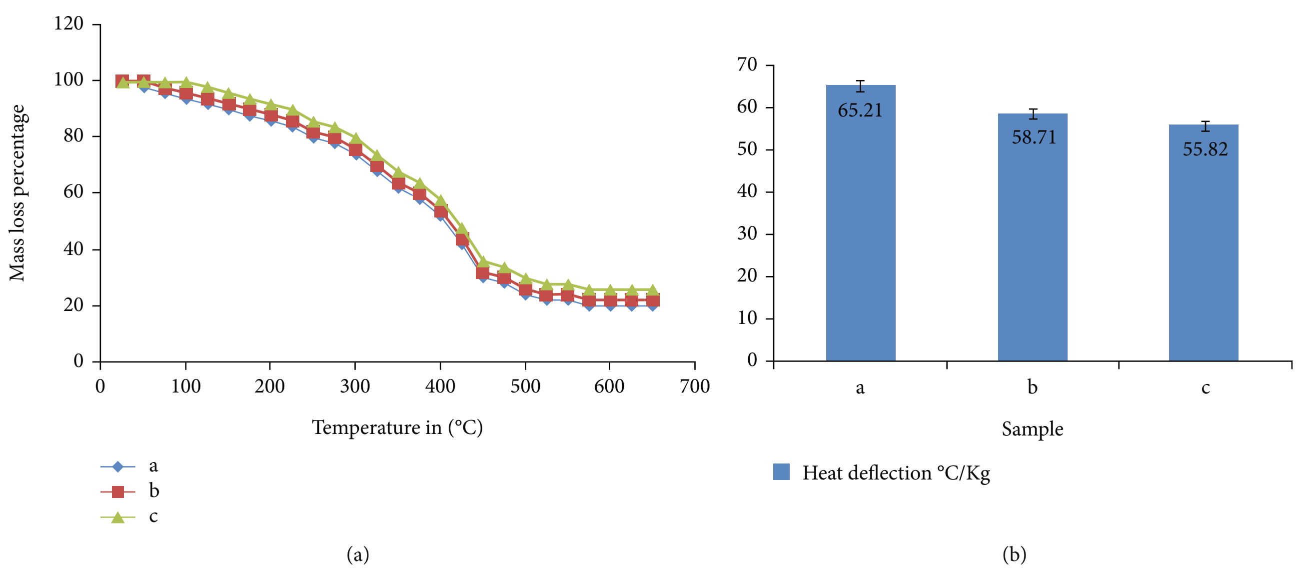

Figure 3: (a) Thermal adsorption behaviour on mass loss of epoxy hybrid composites. (b) Heat deflection temperature of epoxy hybrid composites.

of the jute/sisal/E-glass fibre-bonded epoxy hybrid composite sample a show a significant decomposition rate with 20% mass loss on more than 400°C, and the sample b (0/90-degree orientation) epoxy hybrid composite shows a similar trend of the decomposition rate with improved thermal stability at 25% mass loss during examination at high temperature (more than 400°C). The materials degrade at high temperatures via mass loss due to the volatility of the fabric material in epoxy [23, 24]. It is observed from Figure 3 that the epoxy hybrid composite with intralaminar orientation of sample c shows a minimum mass loss during the high thermal adsorption studies as compared to that of sample b. The decomposition due to mass loss of the glass fibre is more significant than the decomposition of natural fibre. However, all the composites are shown with a downtrend inclination curve. The maximum thermal stability was observed on the intralaminar composite that is used as a good insulator for energy storage applications.

3.1.2. Heat Deflection Temperature. Figure 3(b) represents the heat deflection temperatures of epoxy hybrid composites using various fibre orientations of jute/sisal/E-glass fibre. The heat deflection of the epoxy hybrid composite sample a has a higher value of 65.21 ± .09 ∘ C/kg. The higher heat deflection is due to the 0-degree orientations of the jute/sisal/E-glass fibre being able to transfer a large amount of heat, resulting in variations of the internal structure like decomposition. The heat deflection of sample b is limited by 11% compared to that of the epoxy hybrid composite sample b. The most negligible heat deflection is 55.82 ± 1.02 ∘ C/kg found on epoxy hybrid composite sample c, which is limited by 17% compared to sample a. The 0- and 90-degree cross-positioned fibre has to delay the heat transfer and be stable at varied temperatures. However, the epoxy laminate's heat deflection depends on the selection of fibre, orientations, and processing [24, 27]. Control of the thermal behaviour is the primary reason for the thermal stability of the E-glass fibre's intraorientation. It may depend on thermal aging and reinforced fibre processing [28].

3.2. Tensile Strength of Hybrid Composites. The 300 mm × 25 mm × 4 mm test samples were evaluated based on the ASTM D3039 standard using the UTM tensile test machine with a 5 mm/min cross-slide speed. The tensile strength of the developed epoxy hybrid composite using different fibre orientations of jute/sisal/E-glass fibre is shown in Figure 4. The three trials from each sample (a, b, and c) are considered for the tensile strength evaluation, and their mean value is taken. It is noted from Figure 4 that the tensile strength of the hybrid composite significantly varies due to the orientations of the fibre in the epoxy matrix. However, the fibre orientations are one reason for enhancing mechanical properties [7–9]. The tensile strength of sample a is found to be 48.12 ± 1.78 MPa, and the tensile strength of the composite is increased by 15.8% on the 0- and 90-degree orientations of the fibre (sample b). The improvement in tensile strength of the composite is due to the orientations of the fibre and processing of the composite [24]. The maximum tensile strength of 61.91 ± 2.1 MPa is measured on the intralaminar composite (sample c) fabricated with the jute/sisal/E-glass fibre-bonded epoxy. It was the intrafabric combinations that resist the maximum tensile load and the tensile fracture. The maximum tensile strength was enhanced by 28.65% compared to that of the sample a epoxy hybrid composites as shown in Figure 4.

3.3. Flexural Strength of Hybrid Composites. Figure 5 depicts an epoxy hybrid composite's flexural strength with different jute/sisal/E-glass fibre orientations. The flexural strength of the epoxy hybrid composite sample a is 56.91 ± 1.44 MPa, and 77.85 ± 1.40 MPa is obtained by the 0- and 90-degree orientations of the jute/sisal/E-glass fibre-bonded epoxy hybrid composite sample b. The improvement of flexural strength is due to the adequate bonding strength between the matrix and fibre, thus resisting the high tensile force. The composite's flexural strength may vary due to fibre compositions, laying method, and the second phase reinforcement selection [11–13]. However, the flexural strength of the composite has been related to the selection fibre and its sequence [15, 16]. The flexural strength of the epoxy hybrid composite sample c synthesized using the jute/sisal/E-glass fibre as the intralayer is found at a maximum strength of

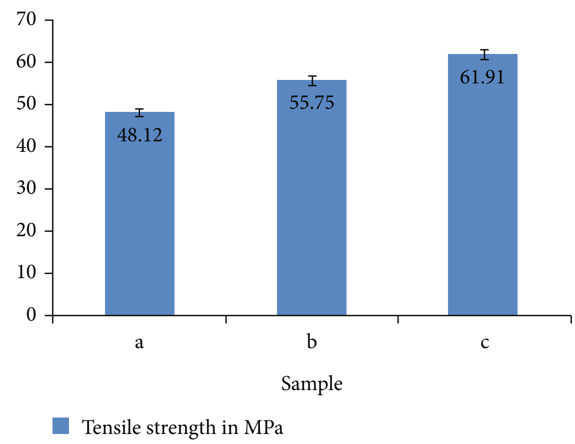

Figure 4: Tensile strength of epoxy hybrid composites.

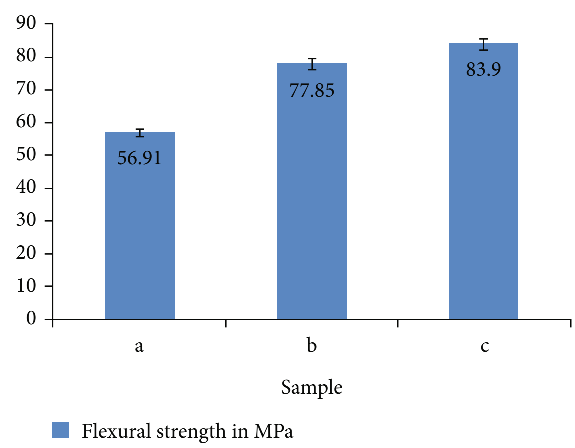

Figure 5: Flexural strength of epoxy hybrid composites.

83.9 ± 1.21 MPa. Flexural strength enhancement is mainly attributed to the content of E-glass fibre presence in the jute/sisal laminate. The intralaminate is one of the primary reasons for the increased flexural strength of the composite. One of the researchers reported a similar report while evaluating a polymer composite bonded by natural fibre/E-glass fibre [18, 19]. The highest flexural strength is found on the intralaminar composite with good bonded structure. The results revealed that the intralaminar composite flexural strength is higher than the value of others. The flexural strength of the intralaminar composite is increased by 47% compared to that of the sample a epoxy hybrid composites.

3.4. Impact Strength of Hybrid Composites. The impact strengths of the different orientations of the jute/sisal/E-glass fibre-bonded epoxy hybrid composite are represented Figure 6. Similar mechanical behaviour is observed in the impact strength of the epoxy hybrid composite. The impact toughness of the epoxy hybrid composite sample a is evaluated as 560.78 J/m, while the that of the epoxy hybrid composite sample b is increased by 18.22%. The presence of natural jute and sisal fibre is the primary reason for increased impact strength, because natural fibres have naturally good toughness, high energy-absorbing capacities, and high stiffness compared to synthetic fibres [18–24]. The highest impact strength is

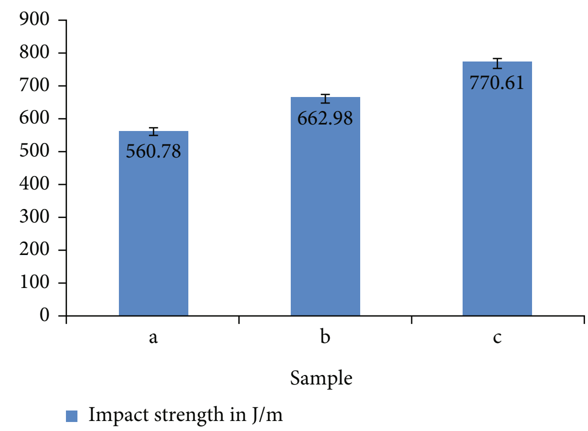

Figure 6: Impact strength of epoxy hybrid composites.

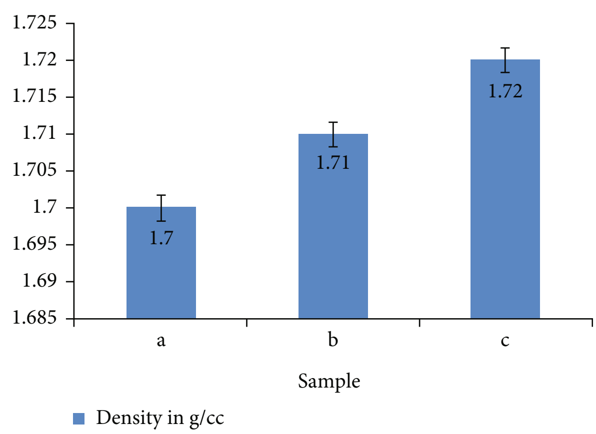

Figure 7: Density of epoxy hybrid composites.

observed in Figure 6, in which the composite contains intralaminar orientations resulting in good impact strength of 770.61 ± 1.31 J/m and improved energy-absorbing capability of 37.41% compared to those of sample a. This is due to the effective layer having been enhanced in the laminar fabric. Thus, the intralaminar-fabricated hybrid composite can withstand high-impact energy during the high-impact loading.

3.5. Density of Hybrid Composites. The densities of the different orientations of jute/sisal/E-glass fibre-bonded epoxy hybrid composite are represented in Figure 7. It is observed from Figure 7 that there are no significant variations found on the epoxy hybrid composite. The density of the epoxy hybrid composite sample a is found to be 1.7 ± 0.81 g/cc, and 1.71 ± 0.78 g/cc is measured for the 0- and 90-degree orientations of the jute/sisal/E-glass fibre-bonded epoxy hybrid composite sample b. For sample c, minor variations of 1.11% in its density were observed compared to sample a. The minor variations in density are due to similar constitutions but with changes in orientations.

4. Conclusions

The epoxy hybrid composite was successfully synthesized via the wet filament-winding process using different orientations of the jute/sisal/E-Glass fibre, and its thermomechanical behaviour was studied. The following conclusions are mentioned:

(i) Consistent among the fabric orientations of the epoxy hybrid composites, the intralaminar composite enhanced thermal adsorption and mechanical properties

(ii) The density of the sample c epoxy hybrid composite is the least (1.72 g/cc)

(iii) The thermal gravimetric analysis of the thermal adsorption properties of sample c found that the reduced decomposition rate due to mass loss of the epoxy hybrid composite was less than 20% at more than 400°C

(iv) The sample c showed that the minimum heat deflection is $55.82 \pm 1.02 \circ$C/kg and is limited by 17% compared to sample a

(v) The tensile, flexural, and impact strengths of the epoxy hybrid composite sample c is higher than those of sample a and sample b. They were improved by 28.65%, 47%, and 37.41%, respectively, compared to the sample a epoxy hybrid composite

(vi) The enhanced sample c epoxy hybrid composite is recommended for thermal insulator applications

Data Availability

All the data required are available within the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] R. Z. A. A. Ramadhan, A. R. Abu Talib, A. S. Mohd Rafie, and R. Zahari, “High velocity impact response of Kevlar-29/epoxy and 6061-T6 aluminum laminated panels,” *Materials and Design*, vol. 43, pp. 307–321, 2013.

[2] R. Higuchi, T. Okabe, A. Yoshimura, and T. E. Tay, “Progressive failure under high-velocity impact on composite laminates: experiment and phenomenological mesomodeling,” *Engineering Fracture Mechanics*, vol. 178, pp. 346–361, 2017.

[3] R. Venkatesh and S. Siva Chandran, “Magnesium alloy machining and its methodology: a systematic review and analyses,” *AIP Conference Proceedings*, vol. 2473, no. 1, 2022.

[4] O. Faruk, A. K. Bledzki, H.-P. Fink, and M. Sain, “Biocomposites reinforced with natural fibers: 2000-2010,” *Progress in Polymer Science*, vol. 37, no. 11, pp. 1552–1596, 2012.

[5] P. Sahu and M. Gupta, “Sisal (Agave sisalana) fibre and its polymer-based composites: a review on current developments,” *Journal of Reinforced Plastics and Composites*, vol. 36, no. 24, pp. 1759–1780, 2017.

[6] S. Baskar and R. Venkatesh, "Thermal management of solar thermoelectric power generation," *AIP Conference Proceedings*, vol. 2473, no. 1, 2022.

[7] Y. Swolfs, L. Gorbatikh, and I. Verpoest, "Fibre hybridisation in polymer composites: a review," *Composites. Part A, Applied Science and Manufacturing*, vol. 67, pp. 181–200, 2014.

[8] T. Gurunathan, S. Mohanty, and S. K. Nayak, "A review of the recent developments in biocomposites based on natural fibres and their application perspectives," *Composites. Part A, Applied Science and Manufacturing*, vol. 77, pp. 1–25, 2015.

[9] Y. Li, Y.-W. Mai, and L. Ye, "Sisal fibre and its composites: a review of recent developments," *Composites Science and Technology*, vol. 60, no. 11, pp. 2037–2055, 2000.

[10] R. Zah, R. Hischier, A. L. Leão, and I. Braun, "Curaua fibers in the automobile industry - a sustainability assessment," *Journal of Cleaner Production*, vol. 15, no. 11-12, pp. 1032–1040, 2007.

[11] J. Isaac Premkumar, A. Prabhu, V. Vijayan, and R. Venkatesh, "Combustion analysis of biodiesel blends with different piston geometries," *Journal of Thermal Analysis and Calorimetry*, vol. 142, no. 4, pp. 1457–1467, 2020.

[12] A. Ramzy, D. Beermann, L. Steuernagel, D. Meiners, and G. Ziegmann, "Developing a new generation of sisal composite fibres for use in industrial applications," *Composites. Part B, Engineering*, vol. 66, pp. 287–298, 2014.

[13] S. N. A. Safri, M. T. H. Sultan, M. Jawaid, and K. Jayakrishna, "Impact behaviour of hybrid composites for structural applications: a review," *Composites. Part B, Engineering*, vol. 133, pp. 112–121, 2018.

[14] R. Eslami-Farsani, S. M. Reza Khalili, and M. Najafi, "Effect of thermal cycling on hardness and impact properties of polymer composites reinforced by basalt and carbon fibers," *Journal of Thermal Stresses*, vol. 36, no. 7, pp. 684–698, 2013.

[15] M. Najafi, S. M. R. Khalili, and R. Eslami-Farsani, "Hybridization effect of basalt and carbon fibers on impact and flexural properties of phenolic composites," *Iranian Polymer Journal*, vol. 23, no. 10, pp. 767–773, 2014.

[16] R. A. Braga and P. A. A. Magalhaes Jr., "Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites," *Materials Science and Engineering: C*, vol. 56, pp. 269–273, 2015.

[17] M. Shamsuyeva, O. Hansen, and H. Endres, "Review on Hybrid Carbon/Flax Composites and Their Properties," *International Journal of Polymer Science*, vol. 2019, Article ID 9624670, 17 pages, 2019.

[18] D. Cavalcanti, M. D. Banea, J. Neto, R. Lima, L. F. M. da Silva, and R. Carbas, "Mechanical characterization of intralaminar natural fibre-reinforced hybrid composites," *Composites. Part B, Engineering*, vol. 175, article 107149, 2019.

[19] B. T. Ferreira, L. J. da Silva, T. H. Panzera, J. C. Santos, R. T. S. Freire, and F. Scarpa, "Sisal-glass hybrid composites reinforced with silica microparticles," *Polymer Testing*, vol. 74, pp. 57–62, 2019.

[20] T. Maridurai and R. Venkatesh, "Review on direct steam generation using concentrated solar collectors," *AIP Conference Proceedings*, vol. 2473, no. 1, 2022.

[21] M. Boopalan, M. Niranjanaa, and M. Umapathy, "Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites," *Composites. Part B, Engineering*, vol. 51, pp. 54–57, 2013.

[22] R. Venkatesh and N. Karthi, "Synthesis and Adsorbent Performance of Modified Biochar with Ag/MgO Nanocomposites for Heat Storage Application," *Adsorption Science & Technology*, vol. 2022, Article ID 7423102, pp. 1–14, 2022.

[23] M. H. Zin, K. Abdan, and M. N. Norizan, "The effect of different fibre loading on flexural and thermal properties of banana/pineapple leaf (PALF)/glass hybrid composite," in *In Structural Health Monitoring of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*, Elsevier, Amsterdam, The Netherlands, 2019.

[24] M. Gupta, "Thermal and dynamic mechanical analysis of hybrid jute/sisal fibre reinforced epoxy composite," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 232, pp. 743–748, 2018.

[25] R. Venkatesh, S. Manivannan, P. Sakthivel, V. Vijayan, and S. Jidesh, "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, pp. 1246–1258, 2022.

[26] T. Behzad and M. Sain, "Measurement and prediction of thermal conductivity for hemp fiber reinforced composites," *Polymer Engineering Science*, vol. 12, pp. 977–983, 2007.

[27] A. Sayyidmousavi, H. Bougherara, S. R. Falahatgar, and Z. Fawaz, "Prediction of the effective thermal conductivity of fiber reinforced composites using a micromechanical approach," *Journal of Mechanics*, vol. 35, no. 2, pp. 179–185, 2019.

[28] C. Atasand and A. Dogan, "An experimental investigation on the repeated impact response of glass/epoxy composites subjected to thermal ageing," *Engineering*, vol. 75, pp. 127–134, 2015.