Hindawi
Adsorption Science & Technology
Volume 2023, Article ID 5272245, 7 pages
https://doi.org/10.1155/2023/5272245

*Research Article*

# Mechanical and Thermal Adsorption Actions on Epoxy Hybrid Composite Layered with Various Sequences of Alkali-Treated Jute and Carbon Fibre

**R. Sasikumar,[1] K. Venkadeshwaran,[2] C. Ramesh Kannan,[3] Melvin Victor De Poures,[4] M. Aruna,[5] N. Mukilarasan,[6] Gopal Kaliyaperumal,[7] and Arundeep Murugan[8]**

[1]*Department of Mechanical Engineering, Erode Sengunthar Engineering College, Erode, 638 057 Tamil Nadu, India*
[2]*Department Mechanical Engineering, JAIN (Deemed-to-be University), Bengaluru, India*
[3]*Department of Mechanical Engineering, SRM TRP Engineering College, Trichy, 621105 Tamil Nadu, India*
[4]*Department of Thermal Engineering, Saveetha School of Engineering, SIMATS, Chennai, 602105 Tamil Nadu, India*
[5]*Faculty of Mechanical and Industrial Engineering, Liwa College of Technology, Abu Dhabi, UAE*
[6]*Department of Mechanical Engineering, Jeppiaar Institute of Technology, Chennai, 631604 Tamil Nadu, India*
[7]*Department of Mechanical Engineering, New Horizon College of Engineering, Bengaluru, Karnataka 560103, India*
[8]*School of Mechanical and Industrial Engineering, Institute of Technology, Debre Markos University, Debre Markos, Ethiopia*

Correspondence should be addressed to Arundeep Murugan; arundeepmurugan@gmail.com

Received 28 October 2022; Revised 19 January 2023; Accepted 28 March 2023; Published 12 April 2023

Academic Editor: Debabrata Barik



Structural applications are accomplished by using a lightweight epoxy matrix bonded with natural jute fibre/synthetic carbon fibre to enhance the physical, mechanical, and thermal properties obtained by different sequences of alkali-treated jute fibre (J.F.)/carbon fibre (C.F.) through conventional hand layup technique. The sequences of the sample are named as H1, H2, H3, and H4 layers of JF/JF/JF/JF, CF/CF/CF/CF, JF/CF/CF/JF, and CF/JF/JF/CF. Influences of JF/CF on physical, mechanical, and thermal adsorption properties of the epoxy composite are evaluated and compared. The mechanical tensile performance of the jute fibre-covered (JF/CF/CF/JF) composite H3 sample is augmented by 29% compared to the H4 sample. Similarly, the CF/JF/JF/CF combinations exhibited a higher impact strength of 129.71 KJ/m$^2$. The maximum hardness of 47.12Hv was found on the four-layered carbon fibre. The thermal adsorption actions on developed composites are evaluated by thermogravimetric apparatus (TGA). It is confirmed that the presence of JF/CF in epoxy composites can endure stability at a higher temperature.

## 1. Introduction

The requirement of polymer matrix composites is reinforced with natural, synthetic, and combinations of both natural and synthetic fibre, increasing in the application of structural field owing to lightweight, good strength, enhanced wear characteristics, superior corrosion resistance, and good toughness [1–5]. Natural fibres (jute, bamboo, flax, coir, and bagasse) can overcome synthetic fibre drawbacks like cost, short life span, nonbiodegradable, and ecofriendly. Using natural fibres facilitates better alternative reinforcements for the polymer matrix composite, gaining advantages on low cost, lightweight, enhanced stiffness, renewable, and nonpollutants [6–8]. While compared to the different varieties of natural fibres listed above, the jute fibre has the highest stiffness and reduces the combined weight [9]. However, it has low impact strength and, owing to high water absorption properties, results in poor interfacial bonding strength [10]. The combinations of natural jute and synthetic fibres are familiar in marine, defence, aerospace, and structural applications due to their excellent bonding strength, enhancing mechanical and thermal performance. However, synthetic fibre is costlier than natural fibre [11–13]. The suggestion by most of the reviewers is that the combinations of natural and synthetic fibre in a solo matrix lead to increases in the balancing properties of mechanical as well as cost [14–16]. The mechanical characteristics of jute and glass fibre-reinforced hybrid composite were studied with different fabric conditions. The glass fibre in the above jute fibre resulted in superior mechanical properties of 121 MPa [17]. The mechanical properties of jute and glass fibre-reinforced hybrid composite may vary due to the stacking positions of fibres. The hybrid composite layer containing glass/jute/jute/glass showed good flexural strength (3.35GPa) and high mechanical performance compared to other laminates [18]. The flax-reinforced polymer matrix composite is hybridization with carbon fibre and shows a higher tensile strength of 215 MPa [19]. The various jute/glass/carbon composite layers are embedded with epoxy resin. The presence of carbon shows a higher flexural strength, and the glass fibre withstands maximum impact strength [20]. The jute fibre-reinforced polymer matrix composite developed by the vacuum resin technique results in an increased modulus of elasticity (0.06 mm) and strength composite (125 MPa) [21]. The maximum flexural strength has been attained by the lamination of multilayer jute/glass/epoxy [22]. The standard of ASTM results evaluating the prepared polyester/jute fibre composites showed that the presence of jute fibre in polyester matrix owned good tensile strength, stiffness, and thermal adsorption properties [23]. The polyester composite enriched with two different layers of jute/glass and jute/carbon makes a practical impact and tensile strength performance.

Carbon increases tensile strength, and glass fibre shows extreme impact strength compared to monopolyester [24]. The combination of natural bamboo fibre bonded with glass fibre hybrid polypropylene matrix composite has enhanced thermal stability and can carry maximum degradation temperature for more than 500°C with reduced weight loss [25]. Based on the above existing literature reported by many researchers, the multilayer fabric sequence has increased the feasibility of composite life with superior properties, and hybridization with synthetic fibre increases the quality of composite in hybrid. So, the present work is to fabricate the different layer sequences of alkali-treated JF/CF-reinforced epoxy composite via hand layup technique to obtain a hybrid composite with increased mechanical and thermal adsorption performance. Correspondingly, the composite's hardness, impact, and tensile strength are examined by E384, D6110, and D309 of ASTM standard.

## 2. Materials and Experimental Details

*2.1. Selection of Materials.* The favourite epoxy resin (R101) and (H101) hardener are considered the primary adhesive materials to acquire an excellent interfacial between fibres. The combinations of epoxy additives are the right choice for bonding both natural and synthetic fibre in a single mat resulting in balanced mechanical properties [14–16]. The 10 : 1 mixing ratio was followed as R101 and H101, respectively. Epoxy resin is a standard resin available at a low cost and forms any shape easily [22, 26]. The $2 \times 2$ fabric plain bidirectional woven jute and twill weave carbon fibre are chosen as secondary materials. The jute fibre owing to the highest stiffness with reduced density results in reduced combined weight. The carbon fibre leads enhance the thermal and mechanical properties [9]. The physical and mechanical properties of the jute/carbon fibre fabric are specified in Table 1.

*2.2. Chemical Treatment of Jute Fibre.* The natural jute fibres had good moisture-absorbing capability because of their hydrophilic properties. It may affect the polymer matrix, which results in poor adhesive and mechanical properties [7, 9]. The above fibre has been treated by different processing techniques to overcome the drawbacks. The chemical processing of jute fibre facilitates excellent quality compared to traditional methods. It results in decreased dust particles and impurities. Various chemical treatments like acetylation, alkali, methacrylate, sodium chlorite, and enzyme enhance the compatible action [27, 28]. Among the various processes reported above, the alkali route is practical, economical, and suitable for all types of natural fibre. The alkali treatment offers excellent interaction between polymer matrix and secondary phase fibre, thermally stable, and good thermal resistance [29]. The alkalization process treats the current research chosen jute fibre. Initially, the jute fibres were immersed in 10 wt% of NaOH-based solution for 120 mins, and every 30 mins, it was refreshed by using 5 litres of distilled water. After the alkali treatment, it was kept in an electric oven and maintained at 55°C for 5 hrs to remove the moisture content. Finally, the treated jute fibres are formed by shrinkage-free structure.

*2.3. Preparation of Alkali-Treated Jute with Carbon Fibre Epoxy Composites.* The present experimental work follows the basic hand layup technique to prepare the epoxy hybrid composite layering with four varieties of fabric sequences of alkali jute and carbon fibre at an elevated temperature of $25 \pm 3$°C as mentioned in Table 2.

Figure 1 shows the flow process diagram for the epoxy hybrid composite fabrication. Initially, the alkali-treated jute and carbon fibre fabric mat are sized 350 mm × 350 mm and formed by the different fabric sequences mentioned above in Table 2, the different J.F. and C.F. sequences of (4 layers) layers are formed by using conventional low-cost hand layup technique. The treated jute/carbon fibre mat is kept in an electric oven separately and preheated to 65°C at 10 hrs to eliminate the wettability of fibre. The H1 hybrid composite is prepared by using J.F. as the first layer. The epoxy and hardener are mixed with a ratio of 10 : 1 with manual stirring for 15 mins. To continue, the epoxy is applied over the first jute fibre layer, and layer 2 (J.F.) is placed over layer 1 (J.F.) with an applied compressive load of 50 kg. It helps to increase the adhesive properties and reduce the pores.

Similarly, layer 3 (J.F.) and layer 4 (J.F.) are formed with a thickness of 10 mm, and the final synthesized composite was cured at 25°C for 1 day. Afterward, it is placed in the oven for postcuring treatment at 45°C for 5 hrs. It helps to increase the bonding strength and increase the compact ratio. A similar procedure is repeated for H2, H3, and H4 samples. ASTM test standards shape the developed hybrid composites H1, H2, H3, and H4.

Table 1: Physical and mechanical properties of jute/carbon fibre fabric.

| Properties | Unit | Jute fibre | Carbon fibre |
|---|---|---|---|
| Physical | | | |
| Density | g/cc | 1.5 | 1.8 |
| Mechanical | | | |
| Tensile strength | MPa | 390 to 770 | 3490 to 4990 |
| Young's modulus | GPa | 10 to 33 | 260 |
| Elasticity | % | 1.8 | 1.8 |

Table 2: Fabric sequences of alkali-treated J.F./C.F. hybrid composites.

| Sample code | Fabric sequences (J.F.: jute fibre; C.F.: carbon fibre) | | | |
|---|---|---|---|---|
| | Layer 1 | Layer 2 | Layer 3 | Layer 4 |
| H1 | J.F. | J.F. | J.F. | J.F. |
| H2 | C.F. | C.F. | C.F. | C.F. |
| H3 | J.F. | C.F. | C.F. | J.F. |
| H4 | C.F. | J.F. | J.F. | C.F. |

*2.4. Characterization of Hybrid Composite.* The developed fibre hybrid composites were subjected to various characteristics study. The ASTM-E384 test standard examines the hybrid composite's micro Vickers hardness number (VHN). The VHN test samples are polished with different emery sheets and fine polish is done by double disc polishing apparatus configured with velvet cloth. The polished test samples are examined by pyramid-type indenter configured with a diamond tip with an angle of 136° at 100 grams load under 10 sec dwell time. The Charpy impact strength of produced hybrid composites is tested by ASTM D6110 standard via an impact tester configured with 300 J capacity. The developed hybrid composite tensile strength is evaluated by UTM tensile machine with 10 mm/min cross-slide speed. The ASTM D3039 standard is followed to estimate the tensile strength of hybrid composites. The dimension of the tensile sample (ASTM D3039) is 300 mm × 25 mm × 4 mm, respectively. The effect of alkali-treated jute and carbon fibre in epoxy composite with degradation is calculated from a thermogravimetric apparatus configured with 22°C to 850°C at a 23°C constant heat flow rate.

## 3. Results and Discussions

*3.1. Micro Vickers Hardness of Hybrid Composites.* Figure 2 illustrates the micro Vickers hardness of epoxy hybrid composite layered with various jute and carbon fibre. It is noted that the micro Vickers hardness number of pure jute fibre H1 samples shows a lower hardness value (26.12 ± 1.18) compared to the remaining samples.

Similarly, four layers of carbon fibre with epoxy show 35.69 ± .34 Hv. So, the effect of interfacial bonding between J.F. to J.F. and C.F. to C.F. is low. It was due to their similar layer may slip and create a poor interfacial action during high tensile load, resulting in reduced mechanical properties [17]. The hybrid composites H3 and H4 show good hardness and are much higher than the H1 and H2 samples. The higher hardness of 47.12 ± 1.18 Hv. It improved by 80.3% and 32% compared to H1 and H2 samples. The increase in hardness value mainly depends on the stacking position of jute and carbon fibre, which was placed by bidirection orientations. Moreover, the fabric combinations with CF/JE/JE/CF sequence (bidirectional mat bonding with epoxy) can resist the indentation against the diamond indenter so that the fabric makes an adequate interfacial strength as considerable error variance in hardness of 1.18 Hv.

*3.2. Impact Toughness of Hybrid Composites.* Figure 3 shows the impact toughness of jute/carbon fibre layered with epoxy matrix hybrid composite. The impact toughness of H1 (JE/JE/JE/JE) is 41.78 ± 1.28 K.J./$m^2$, and 83.98 ± 2.1 KJ/$m^2$ is noted on pure carbon fibre laminates. The impact strength of carbon laminate epoxy composite is higher than that of pure J.E. layer composite. It was due to their high elastic modulus and high impact load stability [20, 24]. It is seen in Figure 3 that the addition of multifibre fabrics like J.E. and C.F. layers in epoxy shows higher impact strength as compared to H1 and H2 composites. The composite with both ends of J.E. fibre covered with C.F. shows an adequate impact toughness of 129.71 ± 2.5 KJ/$m^2$. So, the end layer of carbon fibre can stand the high-impact load without fracture. The various sequences of jute and carbon fibre fabric make good impact strength. The sample H4 is found to have a maximum impact toughness of 129.71 ± 2.5 KJ/$m^2$. It was due to their carbon fibre leading to enhance the epoxy composite, and its bidirectional stacking sequences may be influenced by the absorb the maximum impact energy. It was related to interfacial bonding strength [10]. So, H4 facilitates good mechanical characteristics in structural applications. The complete break occurred on the top of the portion during high-impact load. However, jute and carbon fibre may absorb the maximum impact energy without failure.

*3.3. Tensile Strength of Hybrid Composites.* The tensile strength of the hybrid composite with various fabric sequences of alkali-treated jute (J.F.)/carbon fibre (C.F.) is shown in Figure 4. It varied due to the type of fibre, processing, interfacial bond strength, types of matrix, and sequences of fabric arrangements [18–20]. The tensile strength of the jute layer epoxy hybrid composite is 56.97 ± 2.4 MPa, and 161.39 ± 3.1 MPa is identified on pure carbon sequence with epoxy adhesive. The pure carbon stacking sequence is improved 1.83 times of jute fibre sequence. However, the different layer sequence with two-layer jute/carbon has better tensile strength than pure jute fibre and carbon fibre. The H3 sample is noted in Figure 4 as the highest value compared to others. The two outer jute fibre sequences covered with carbon sequence increased by 24% compared to the carbon layer covered with jute fibre. It was due to the arrangements of jute fibre in carbon fibre that gained strong interfacial bonding leading to increased mechanical strength. The results revealed in Figure 4 that the tensile strength of

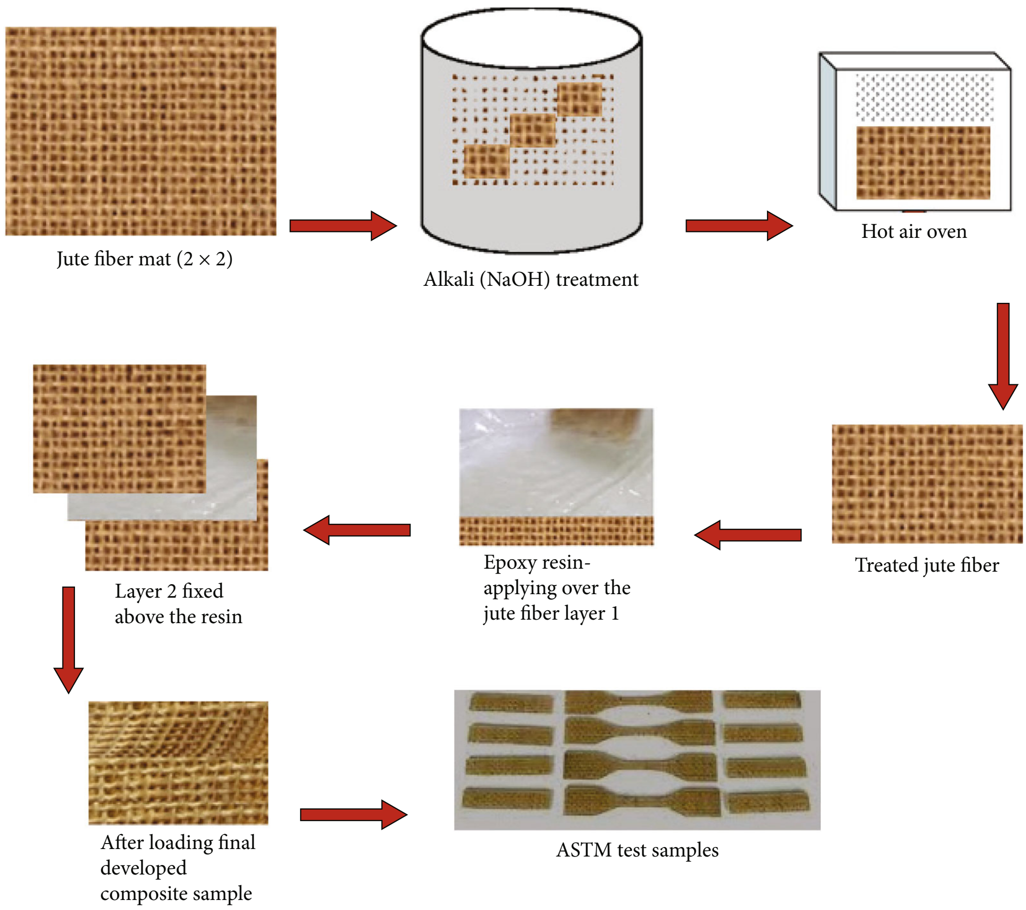


FIGURE 1: Process layout for epoxy hybrid composite fabrication.

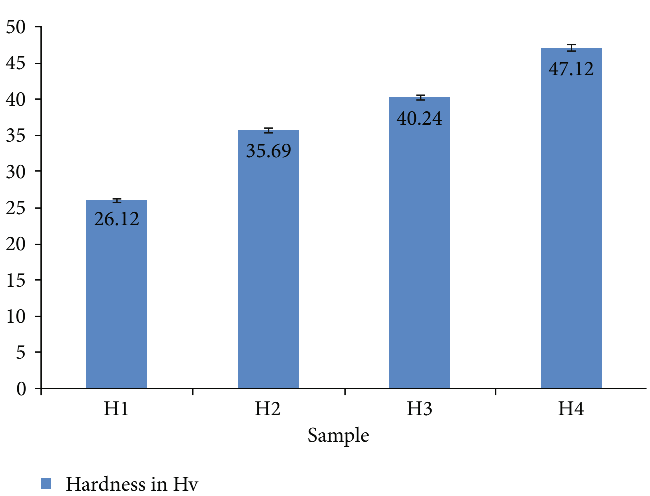


FIGURE 2: Hardness of hybrid composites.

the composite might differ due to test conditions and natural fibre treatment.

Therefore, the outer layer of the composite leads an essential role in tensile load during the evaluation of tensile strength. The strong J.E. layer perfectly bonded with carbon fibre may increase the tensile strength of composites. The applied load and curing time was the main reason for increased adhesive between matrix and fibre, which resulted in increased tensile strength. Bidirectional fibre is another reason for higher tensile strength because the layerable resists the internal movement on a higher tensile load. Sample H4 shows a decreased tensile strength of $235.97 \pm 1.98$ MPa. It was because carbon fibre may be deboned from the jute fibre during high tensile load. Because the outer carbon layer has a chance to break on high tensile load [9].

*3.4. Thermal Adsorption Properties of Hybrid Composite.* The thermal stability and mass loss due to decomposition during high temperature on thermal adsorption performance of epoxy composite layers with jute and carbon fibre estimated by thermogravimetric apparatus configured with 22°C to 850°C at 23°C constant heat flow rate. Figure 5 represents the thermogravimetric thermal stability analysis related to mass loss of untreated jute fibre, alkali-treated jute fibre, and epoxy hybrid composite. The current experiment on the thermal degradation of composite is estimated with 28°C to 550°C at a 23°C constant heat flow rate. It was noted during the thermogravimetric analysis that the three variants of decomposition, like first stage weight loss, are identified as the temperature range of 28°C to 131°C, the second phase of decomposition on mass loss of composite progressively

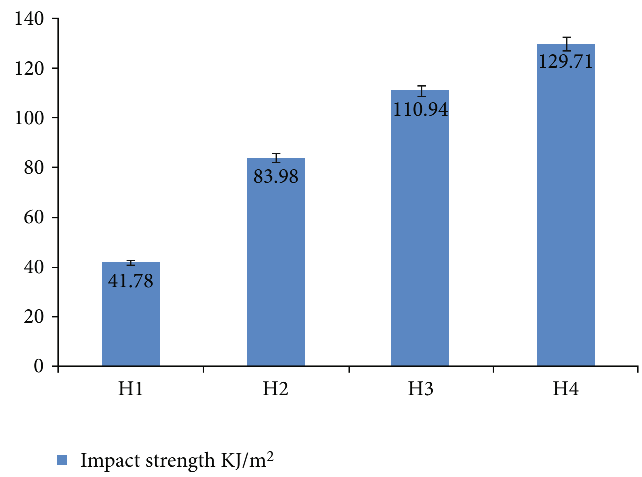


Figure 3: Impact toughness of hybrid composites.

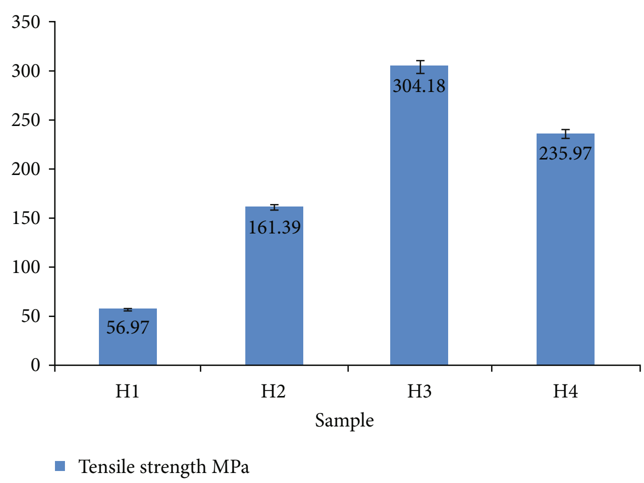


Figure 4: Tensile strength of hybrid composites.

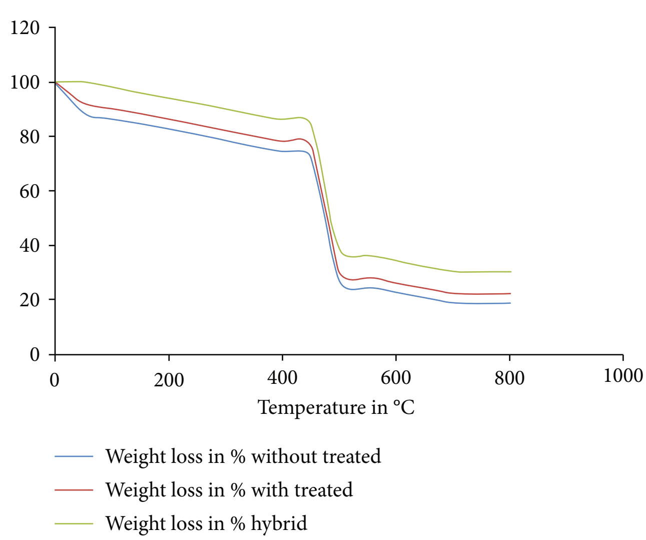


Figure 5: Thermal adsorption effect on thermal stability related to the mass of untreated, treated, and hybrid jute fibre composites.

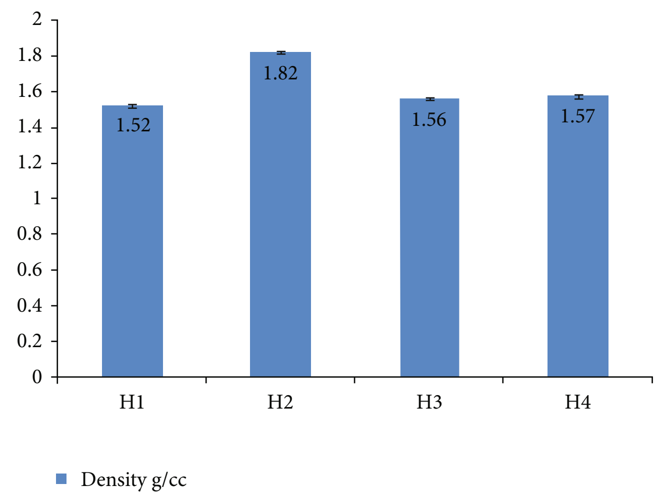


Figure 6: Density of hybrid composites.

reduced with increasing the temperature of 148°C to 286°C, and correspondingly, decomposition of final stage shows a light mass loss. However, Figure 5 illustrates that the mass loss of untreated, treated, and hybrid composite shows progressive mass loss during increased decomposition on increased thermal conditions. The similar mass loss curved profile is followed by stages 1, 2, and 3, respectively. But the initial stage shows fast decompositions on untreated fibre, the next stage shows increased thermal stability with reduced mass loss (24, 28, and 36%) at 550°C compared to the initial stage, and the last stage on hybrid composite shows good thermal stability with reduced decomposition rate and mass loss 78, 82, and 90%. However, the alkali-treated jute fibre with carbon fibre makes higher thermal stability during high-temperature studies. It was improved by 12% as compared to untreated fibre. The weight loss percentage of hybrid composite is much lower than the untreated and treated fibre.

*3.5. Density of Hybrid Composite.* Figure 6 illustrates the density of an epoxy hybrid composite consisting of different jute/carbon fibre layers. The combinations of jute and carbon fibre vary the density of the composite. However, it has to obey the rule of mixture. In the jute fibre combinations of 4 layers (J.F.), the H1 sample was found as $1.52 \pm 1.01$ g/cc.

Similarly, in the carbon fibre combinations of 4 layers (C.F.), the H2 sample observed an increased density value of$1.82 \pm 0.92$ g/cc. The increase in composite density was due to the presence of carbon fibre. The intercombinations of H3 and H4 samples are noted as $1.56 \pm 0.28$ g/cc and $1.57 \pm 0.87$ g/cc. The optimum properties of the H3 sample are found to be lightweight, and its weight is reduced by 17% as compared to the H2 sample.

## 4. Conclusions

In the current experimental investigations of alkali-treated jute/carbon fibre fabric, a hybrid composite developed effectively via hand layup technique with various sequences of

J.E. and C.F. The effect of bidirectional fibre orientations with different sequences of J.F. and C.F. on physical, mechanical, and thermal adsorption performance of epoxy hybrid composite was studied by ASTM, and the final decision to the conclusions of results is mentioned below.

(i) The chemical alkali-treated jute fibre enhances the carbon composite with JE/CF/CF/JF (H3) sequences and CF/JF/JF/CF (H4).

(ii) The similar J.F. or C.F. layer shows a low hardness, impact, and tensile strength

(iii) The presence of treated jute fibre in the carbon fibre layer having good mechanical properties like the two-outer layer of carbon fibre circumstance jute fibre hybrid composite (sample H3) found increased hardness and impact strength of $47.12 \pm 1.18$ Hv and $129.71 \pm 2.5$ KJ/m$^2$, respectively

(iv) Similarly, the outer jute layer bonded with internal carbon fabric (sample H3) showed a higher tensile strength of $304.18 \pm 5.4$ MPa and increased 1.83 times jute fibre and 24% H4 sample

(v) The thermal adsorption on thermal stability related to mass loss percentage of untreated, treated, and hybrid composite was studied, and hybrid composite found superior thermal stability at higher temperatures and increased 12% compared to untreated fibre

(vi) The density of the H3 sample is limited by 17% as compared to the H2 sample

## 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] D. Gay, *Composite Materials. Design and Applications*, CRC Press, Boca Raton, FL, 2022.

[2] T. Tang, S. Fang, J. Chen, L. Ma, L. Li, and X. Wu, "Axial compression behavior of recycled-aggregate-concrete-filled GFRP-steel composite tube columns," *Engineering Structures*, vol. 216, article 110676, 2020.

[3] S. Armioun, S. Panthapulakkal, J. Tjong, and M. Sain, "Renewable, recyclable, and lightweight structural prototype for greener automotive interior panels," *SAE World Congress Exposition*, 2004.

[4] M. Jawaid, H. P. S. A. Khalil, A. A. Bakar, and P. N. Khanam, "Chemical resistance, void content and tensile properties of oil palm/jute fibre reinforced polymer hybrid composites," *Material design*, vol. 32, no. 2, pp. 1014–1019, 2011.

[5] S. Marimuthu and R. Venkatesh, "Performance study on glazzed solar air heater for agri products," *Materials Today Proceedings*, vol. 69, pp. 633–636, 2022.

[6] K. Bledzki, S. Reihmane, and J. Gassan, "Properties and modification methods for vegetable fibers for natural fiber composites," *Journal of Applied Polymer Science*, vol. 59, no. 8, pp. 1329–1336, 1996.

[7] R. A. Braga and P. A. Magalhaes, "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.

[8] M. Shamsuyeva, O. Hansen, and H. J. Endres, "Review on hybrid carbon/flax composites and their properties," *International journal of polymer science*, vol. 2019, Article ID 9624670, 17 pages, 2019.

[9] M. A. Elbaky and M. A. Attia, "Water absorption effect on the in-plane shear properties of jute–glass–carbon-reinforced composites using Iosipescu test," *Journal of composite material*, vol. 53, no. 21, pp. 3033–3045, 2019.

[10] S. D. Pandita, X. Yuan, M. A. Manan, C. H. Lau, A. S. Subramanian, and J. Wei, "Evaluation of jute/glass hybrid composite sandwich: water resistance, impact properties and life cycle assessment," *Journal of Reinforced Plastics and Composites*, vol. 33, no. 1, pp. 14–25, 2014.

[11] A. Sobhanadri, G. Senthilkumar, M. Vivekanandan, and R. Venkatesh, "A CFD investigation and heat transfer augmentation of double pipe heat exchanger by employing helical baffles on shell and tube side," *Thermal Science*, vol. 26, no. 2A, pp. 991–998, 2022.

[12] P. S. Ramalingam, K. Mayandi, T. Srinivasan, I. J. Leno, R. Ravi, and G. Suresh, "A study on E-Glass fiber reinforced interpenetrating polymer network (vinylester/polyurethane) laminate's flexural analysis," *Materials Today: Proceedings*, vol. 33, pp. 854–858, 2020.

[13] M. Krishnaraj, R. Arun, and T. Vaitheeswaran, *Fabrication and wear characteristics basalt fibre reinforced polypropylene matrix composites*, SAE Technical Paper, 2019.

[14] 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, no. 4, pp. 1246–1258, 2022.

[15] M. A. Khan, J. Ganster, and H. P. Fink, "Hybrid composites of jute and man-made cellulose fibers with polypropylene by injection moulding," *Composite Part A: Applied science and manufacturing*, vol. 40, no. 6-7, pp. 846–851, 2009.

[16] M. Jawaid and H. P. S. Khalil, "Cellulosic/synthetic fibre reinforced polymer hybrid composites: a review," *Carbohydrate polymers*, vol. 86, no. 1, pp. 1–18, 2011.

[17] K. S. Ahmed and S. Vijayarangan, "Tensile, flexural and interlaminar shear properties of woven jute and jute- glass fabric reinforced polyester composites," *Journal of materials processing technology*, vol. 207, no. 1-3, pp. 330–335, 2008.

[18] R. Gujjala, S. Ojha, S. K. Acharya, and S. K. Pal, "Mechanical properties of woven jute-glass hybrid-reinforced epoxy composite," *Journal of Composite Materials*, vol. 48, no. 28, pp. 3445–3455, 2014.

[19] S. Rajkumar, M. Loganathan, and R. Venkatesh, "Optimization of NACL based spray corrosion test process parameters of heat treated hybrid metal matrix composites," *Bulletin of the Chemical Society of Ethiopia*, vol. 36, no. 4, pp. 903–914, 2022.

[20] M. A. Elbaky, "Evaluation of mechanical properties of jute/glass/carbon fibers reinforced hybrid composites," *Fibre polymers*, vol. 18, no. 12, pp. 2417–2432, 2017.

[21] T. M. Gowda, A. C. Naidu, and R. Chhaya, "Some mechanical properties of untreated jute fabric-reinforced polyester composites," *Composite part A: Applied science and manufacturing*, vol. 30, no. 3, pp. 277–284, 1999.

[22] M. Ramesh, K. Palanikumar, and K. H. Reddy, "Comparative evaluation on properties of hybrid glass fiber- sisal/jute reinforced epoxy composites," *Procedia Engineering*, vol. 51, pp. 745–750, 2013.

[23] M. Vivekanandan, M. Premalatha, N. Anantharaman, R. Venkatesh, and V. Vijayan, "Hydrodynamic studies of CFBC boiler with three types of air distributor nozzles: experimental and CFD analysis," *Journal of Thermal Analysis and Calorimetry*, vol. 148, no. 2, pp. 405–415, 2023.

[24] H. Sezgin and O. B. Berkalp, "The effect of hybridization on significant characteristics of jute/glass and jute/carbon reinforced composites," *Journal of Industrial Textiles*, vol. 47, no. 3, pp. 283–296, 2017.

[25] S. K. Nayak, S. Mohanty, and S. K. Samal, "Influence of short bamboo/glass fiber on the thermal, dynamic mechanical and rheological properties of polypropylene hybrid composites," *Material science and engineering part A*, vol. 523, no. 1-2, pp. 32–38, 2009.

[26] D. Chmielewska, M. Barczewski, and T. Sterzynski, "A new method of curing epoxy resin by using bis(heptaphenylaluminosilsesquioxane) as a hardener," *Polimery*, vol. 58, no. 4, pp. 270–275, 2013.

[27] R. Venkatesh and P. R. Sekaran, "Adsorption and photocatalytic degradation properties of bimetallic Ag/MgO/biochar nanocomposites," *Adsorption Science & Technology*, vol. 2022, article 3631584, pp. 1–14, 2022.

[28] A. Gopinath, M. S. Kumar, and A. J. Elayaperumal, "Experimental Investigations on Mechanical Properties Of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices," *Process Engineering*, vol. 97, pp. 2052–2063, 2014.

[29] D. Ray, M. Das, and D. Mitra, "Influence of alkali treatment on creep properties and crystallinity of jute fibres," *BioResources*, vol. 4, pp. 730–739, 2009.