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Research Article

Synthesis and Experimental Thermal Adsorption Characteristics of Epoxy Hybrid Composite for Energy Storage Applications

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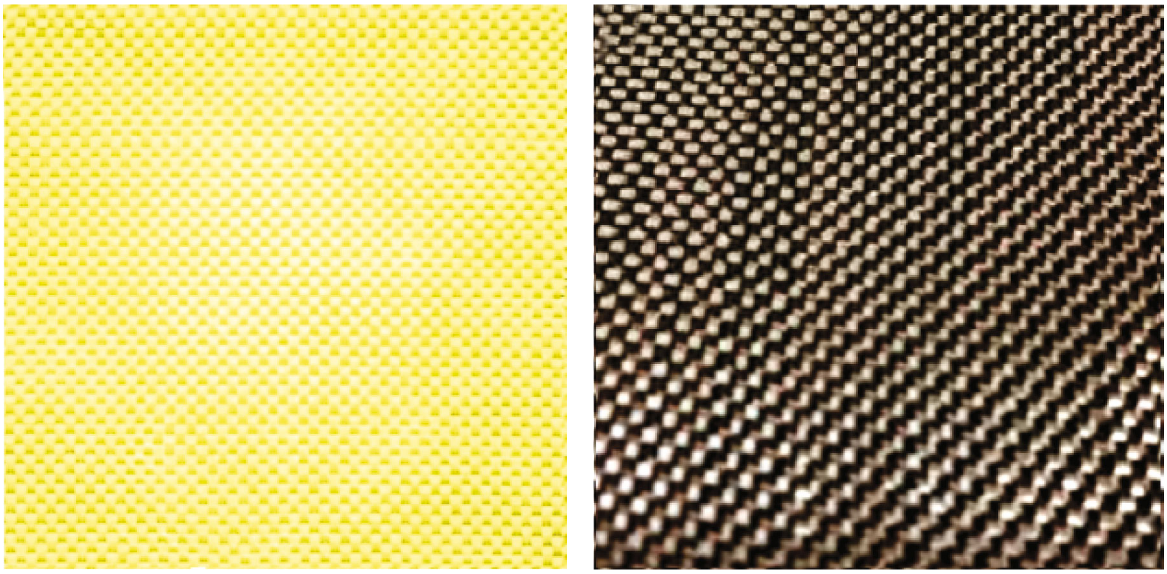
Polymer-based matrix hybrid composites meet their demand in various engineering applications and food industries due to their excellent mechanical, thermal, corrosion, and biodegradable performance. The polymer-based hybrid composites have been a better choice for high thermal insulation at low cost. This experiment attempted to find the thermal adsorption characteristics, heat deflection temperature, linear thermal expansion, and thermal conductivity of epoxy hybrid composites, which contained four different layers of Kevlar and basalt fiber fabricated via a low-cost conventional hand mold layup technique. This experiment revealed that the effect of basalt/Kevlar fiber on epoxy increased thermal performance. The results noted that the hybrid composite consists of less Kevlar fiber with the maximum basalt fiber of sample 4, showed excellent thermal adsorption effect on weight loss limited at 70.98%, and a better heat deflection temperature and11.78×10^{-6}per °C linear thermal expansion were obtained. Sample 3 exhibited a maximum thermal conductivity of 0.251 W/mK. However, the thermal adsorption of hybrid composite has been limited by more basalt fiber, leading to a 1 wt%/°C decomposition rate.

1. Introduction

Great potential with lightweight polymer matrix composites is considered the best alternative for replacing conventional plastic material in several engineering, food, and medical industries. Polymer matrix composites are invented by polymer resin bonded with secondary phase material like fibers. It has been produced quickly using conventional techniques at a reasonable cost. Epoxy resin is mainly used for polymer matrix fabrication to obtain a high feature of mechanical, thermal, and chemical resistance [1, 2]. The polymer composite consists of various laminate fibers and dramatically impacts engineering manufacturing. It engages more percentage of the total production volume in various automotive applications [3]. The advanced grouping of natural and synthetic fiber composites is a better substitution for conventional composites due to their enhanced compatibility with resin [4–6]. More research investigation is done relevant to polymer matrix composite with various combinations of natural and synthetic fibers. The Kevlar/



(a) (b)

Figure 1: Fabric mat (a) Kevlar fiber and (b) basalt fiber.

Table 1: Mechanical and thermal properties of the fabric mat.

Fiber/properties	Density in g/cc	Tensile strength in MPa	Elastic modulus in GPa	Thermal conductivity (W/mK)
Kevlar	1.44	3620	62	0.04
Basalt	2.65	4800	110	1.62

basalt fiber combinations play a vital role in various industrial applications due to their enhanced thermal characteristics compared to other combinations [7–9]. The sandwich-configured Kevlar-flax-epoxy hybrid composite found superior impact and tensile strength [10].

Similarly, the epoxy/basalt fiber composite laminate with various graphene nanopellets (GNP) showed increased tensile, flexural, and impact strength of the composite [11]. Recently, Kevlar has been grouped with aramid fiber, resulting in low density, good thermal behavior, high thermal stability, and high strength. It is used to replace steel material in various applications, like bicycle frames and racing cars [12]. The mixed vinyl ester composite grouping with flax/basalt fiber showed higher tensile strength with limited brittleness and stiffness behavior [13]. The thermal conductivity of hemp-reinforced polymer composite is studied and experimentally measured and compared with that of the poly matrix. It showed good relation between theoretical to actual [14, 15]. The granite/basalt fiber/sandstone-reinforced polymer composite found better thermal stability at 25°C and 1000°C [16]. The E-glass-reinforced epoxy composite was developed via a conventional method to find increased thermal behavior [17]. The impact strength of glass fiber-reinforced polymer laminates shows a better resistive force on high-impact load [18]. The Kevlar-basalt fiber-mapping polymer composite with three layers thick showed better mechanical strength. It is impacted with 40-60 m/sec velocity, increasing the bonding strength [19]. The thermal conductivity of composite varies for the following reasons: fiber orientation, base material, number of layers, and method of composite fabrication [20]. Incorporating fiber content in large volumes can increase thermal characteristics and provide good mechanical strength [21]. The thermal gravimetric analysis of the glass/carbon/Kevlar/polymer matrix hybrid composite showed minimum weight loss during high-temperature evaluation [22]. The following factors may affect the thermal characteristics of the composite fiber: length, diameter, mixing ratio, and defects [23]. The main aim of the experimental work is to evaluate the thermal adsorption characteristics of epoxy composite hybridization with Kevlar/basalt fiber via the conventional hand layup technique. The thermal behavior, like thermal conductivity, heat deflection temperature, and linear thermal expansion of composite, is also evaluated by different thermal conditions.

2. Experimental Details

2.1. Materials. The 400 GSM synthetic basalt and natural Kevlar fibers are chosen as reinforcement, as shown in Figures 1(a) and 1(b). Epoxy resin and hardener were chosen as adhesive materials. Kevlar and basalt fiber combinations improve the composite's thermal stability and impact strength [7–9]. The mechanical and thermal properties of both fibers are listed in Table 1.

2.2. Synthesis of Hybrid Composite. The epoxy resin and hardener mix at a ratio of 15 : 1 through manual stir action. The dimensions of 300 mm × 100 mm × 2 prepare the Kevlar

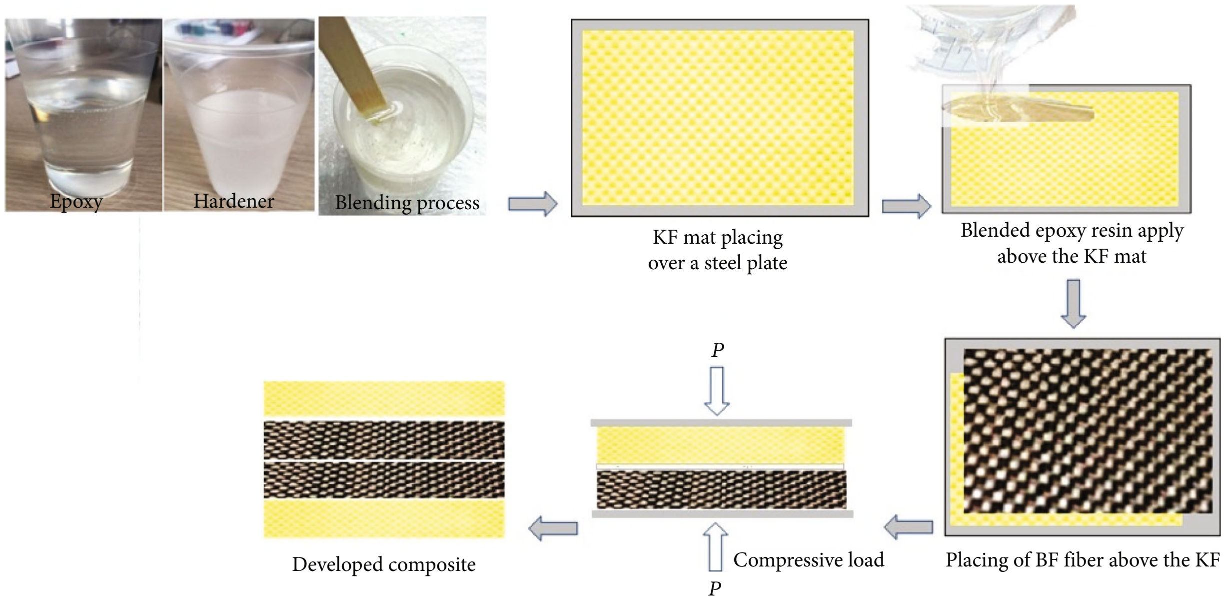


Figure 2: Flow process layout for epoxy hybrid composite fabrication.

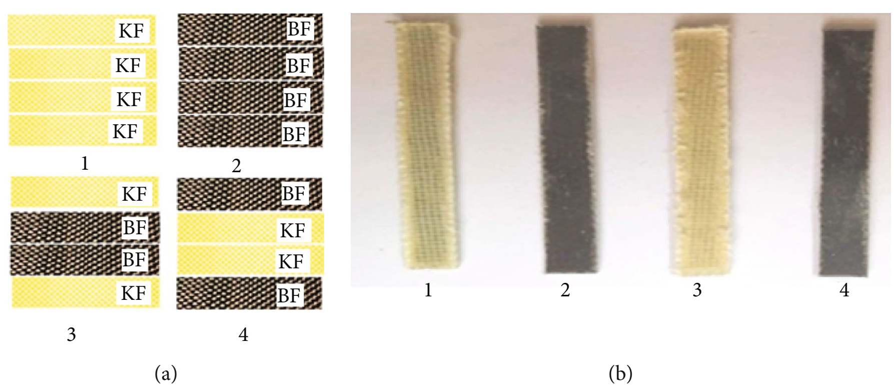


Figure 3: Epoxy hybrid composite. (a) Different stacking sequences of KF/BF on epoxy composite. (b) Developed hybrid composite samples.

and basalt fiber mat mm. The sample 3 hybrid composite fabrication details are shown in Figure 2. Initially, the Kevlar fiber (KF) mat is placed over the flat steel plate, and blended epoxy resin is uniformly laid over the KF mat at 0.5 mm thickness via a hand-operated roller. Similarly, the next basalt fiber (BF) layer is placed perpendicular to the Kevlar fiber over the epoxy layer. The KF and BF with intermediate epoxy resin are compacted by a 1 KN compressive load at 20 mins and cured by an electric oven at 40-55°C. A similar procedure is repeated for the next BF and KF layer of intermediate epoxy resin. The various sequences of Kevlar fiber KF and basalt fiber (BF) with intermediate epoxy resin are illustrated in Figure 3(a), and their developed composites are illustrated in Figure 3(b). The prepared KF/BF/BF/KF composite mat was kept in a hydraulic compression machine configured with a 1-ton capacity. The composite was compressed with an applied compressive force of 1 KN maintained for the next 1 hr. It helps increase adhesive properties [8, 9]. Finally, the developed composites are shaped as per test standards.

3. Results and Discussions

3.1. Thermal Adsorption Properties of Hybrid Composites. The effects of Kevlar and basalt finer on the thermal adsorption behavior of epoxy hybrid composites were evaluated by thermal gravimetric analysis. Figures 4(a)–4(d) depict the thermal adsorption behavior on weight loss during high-temperature decomposition of hybrid composite with different stacking sequences as mentioned in Figure 3(a) (samples 1, 2, 3, and 4).

The decomposition rate of the hybrid composite was measured by its composition, pyrolysis, and material volatility. The composite's thermal adsorption on mass loss decomposition percentage was examined from 25°C to 670°C at a 27°C/min heat flow rate. Normal airflow may lead to material decomposition during inert atmospheric conditions, whereas increased temperature may prevent this [23–25]. The various stacking sequences of KF and BF layer results showed lower weight loss (less than 40%) at higher temperatures (more than 240°C). The thermal adsorption

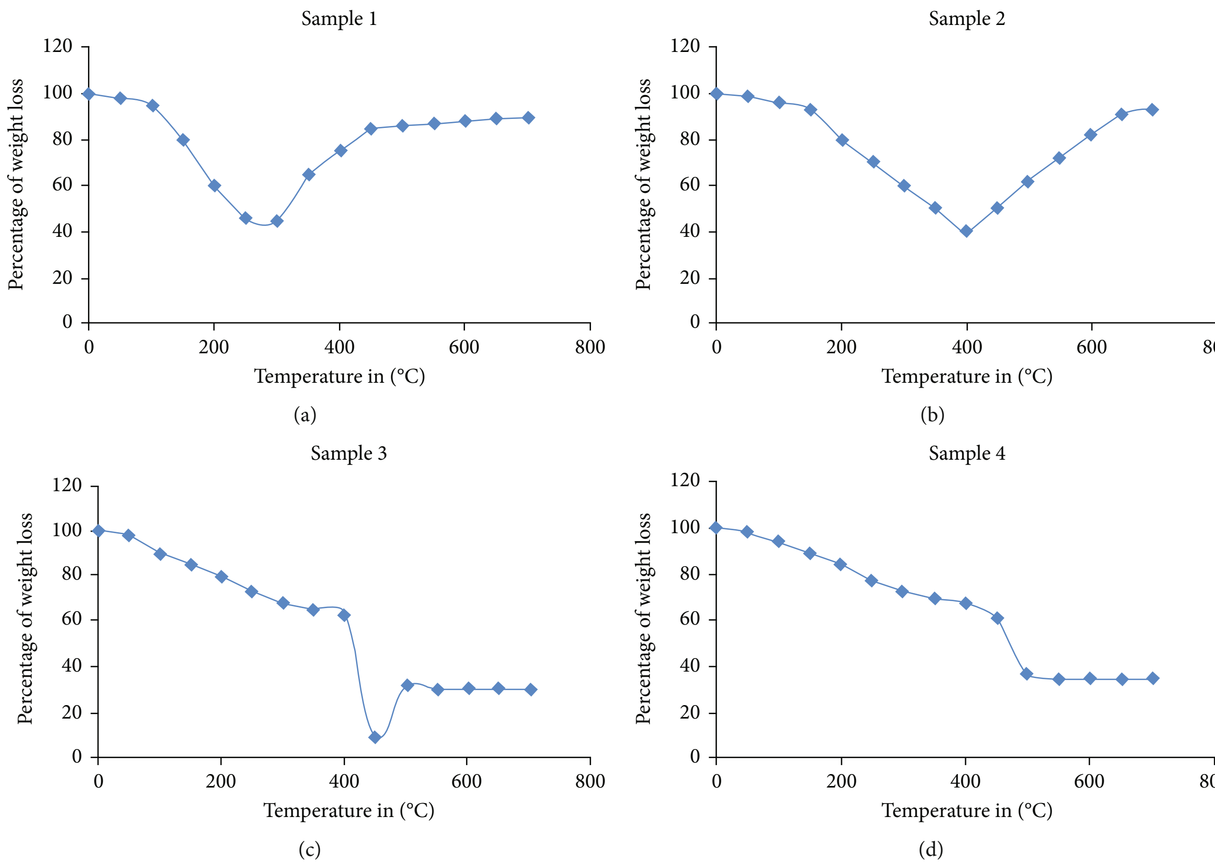


Figure 4: (a) Thermal adsorption on weight loss percentage of hybrid composite sample 1. (b) Thermal adsorption on weight loss percentage of hybrid composite sample 2. (c) Thermal adsorption on weight loss percentage of hybrid composite sample 3. (d) Thermal adsorption on weight loss percentage of hybrid composite sample 4.

behavior varied based on KF and BF stacking sequences. Table 2 depicts the weight loss of a hybrid composite with various stacking sequences, which results in superior thermal adsorption properties. It is observed from Figure 4 and the corresponding Table 2 that the percentage of weight loss due to high-temperature decomposition is 58% related to sequences of hybrid composites. The thermal reactions were observed during the evaluation of thermal adsorption behavior, and the effect of KF/BF on hybrid composite showed an exothermic effect of heat able to decompose the structure. However, stacking different sequences could resist the decomposition rate during high temperatures. It forms V and U curves related to the exothermic effects of Kevlar and basalt fiber. Samples 1 and 2 found as U and V exothermic curves represent the effect of exothermic during the higher temperature of decomposition, and their percentages are mentioned in Table 2. The decomposition rate of sample 4 was limited by 1% as compared to sample 1.

Table 2: Weight-loss percentage of various thermal adsorption conditions.

Sample no.	Weight loss percentage		
	Decomposition	Medium temperature	Residue
1	65.23	75.91	32.81
2	50.29	50.78	30.23
3	66.98	63.7	29.18
4	70.98	67.01	28.78

3.2. Heat Deflection Temperature. Figure 5 illustrates the effect of KF/BF on the heat deflection temperature of an epoxy hybrid composite evaluated by different stacking positions of KF/BF, as shown in Figure 3(a). It is observed from Figure 5 that the heat deflection of epoxy hybrid composite samples 1–4 found a variation value with increased thermal conductivity. The higher heat deflection temperature of 105.74 ± 1.56°C/Kg was identified in sample 1 with its thermal conductivity range of 0.198 W/mK. While compared to sample 1, the heat deflection temperatures of samples 2, 3, and 4 were noted as the decreased value of 66.91 ± 1.29°C/Kg, 71.18 ± 1.72°C/Kg, and 69.23 ± 1.57, respectively. However, the basalt fiber-faced epoxy hybrid composite has a low heat deflection temperature compared to the Kevlar fiber-faced epoxy hybrid composite. The basalt fiber laminates with epoxy resin have performed extreme thermal stability behavior [11].

Sample 2 was noted by a minor heat deflection temperature of 66.91 ± 1.29°C/Kg. It was due to the effect of basalt fiber effectively bonded with epoxy material by an applied compressive load of 1 KN. The basalt fiber exhibited good mechanical and thermal characteristics [24]. The heat

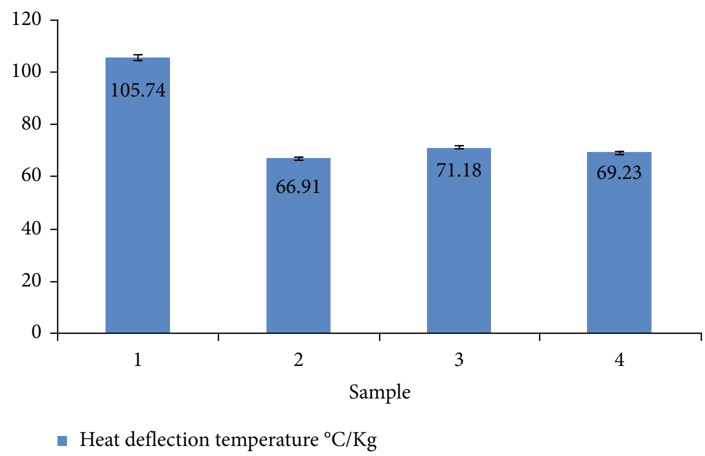


Figure 5: Heat deflection temperature of hybrid composites.

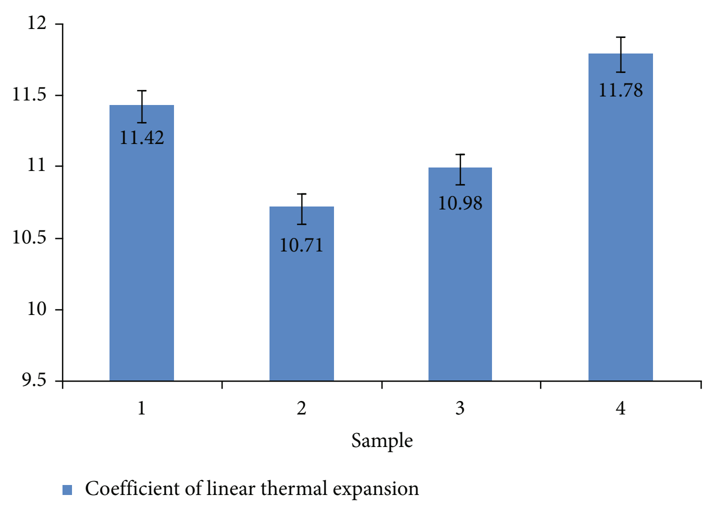


Figure 6: Coefficient of linear thermal expansion of hybrid composites.

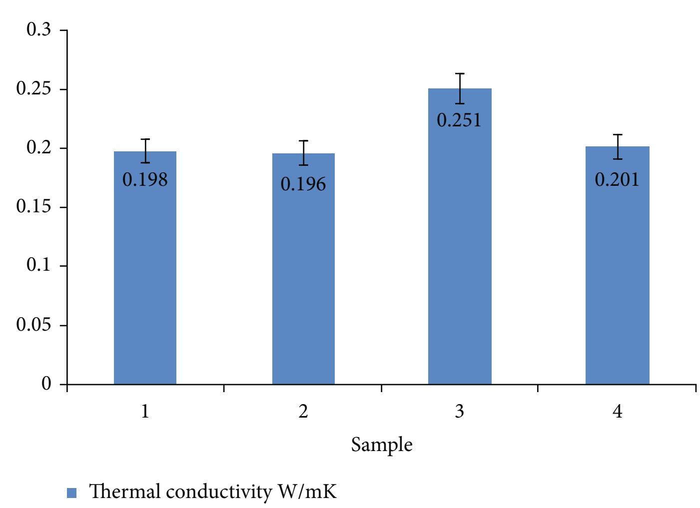


Figure 7: Thermal conductivity of hybrid composites.

deflection evaluation of the composite helps find the thermal stability of the composite [26]. Moreover, the coated ceramic material has to lead to good mechanical and thermal characteristics [27]. Both sample 2 and sample showed the least heat deflection temperature. So these samples may promote good insulation for energy storage applications.

3.3. Coefficient of Linear Thermal Expansion. The coefficient of thermal expansion of various stacking sequences of a developed KF/BF hybrid composite bonded with epoxy was evaluated by the relations between heat supplied and temperature difference. Figure 6 presents the coefficient of thermal expansion of hybrid composites (samples 1, 2, 3, and 4). It is evidenced in Figure 6 that the composite, which contained a multilayer of KF and BF, shows a good coefficient of thermal expansion compared to a similar fiber-fabric hybrid composite. The coefficient of thermal expansion of samples 1 and 2 is found to be 11.42×10^{-6} per °C and 10.71×10^{-6} per °C. Heat transformation is separated by a multilayer fabric mat composite with different sequences. The multifabric arrangement with 0° and 90° orientations makes a perfect heat transfer during the isotropic process [28]. Sample 4 has an excellent thermal expansion coefficient of 11.78×10^{-6} per °C, and effective heat transfer was found between the fabric mats via an epoxy matrix. Kevlar and basalt fiber contribute to thermal expansion with limited effective binding performance. Sample 4 represents that the coefficient of thermal expansion of hybrid composite with basalt fiber-faced epoxy hybrid composites (BF/KF/KF/BF) reduces the effect of maximum heat transformation.

3.4. Thermal Conductivity. Figure 7 depicts the effect of KF/BF on the thermal conductivity of epoxy hybrid composites with different stacking sequences. It is noted from Figure 7 that the hybrid composite with similar layers like KF/KF/KF/KF and BF/BF/BF/BF epoxy hybrid composite samples 1 and 2 showed the most negligible thermal conductivity of 0.198 ± 0.18 and 0.196 ± 0.11 W/mK, respectively. At the same time, the multilayer KF/BF combinations of samples 3 and 4 of the epoxy hybrid composite were found to have good thermal conductivity compared to samples 1 and 2. The composite grouping with KF/BF/BF/KF (sample 3) showed a higher thermal conductivity of 0.251 W/mK. The thermal conductivity of sample 3 was 26.6% higher than that of sample 1. It was due to the effective basalt fiber layer occupied between Kevlar fibers. However, the thermal conductivity of epoxy composites was enriched by Kevlar fiber bonded with epoxy with a BF interlayer. The Kevlar fiber has good thermal conductivity [14, 15, 17].

The stacking thermal gravimetric curve of Kevlar and basalt fibers has a low thermal conductivity compared to other multilayer KF/BF fiber hybrid composites. The Kevlar fiber facilitates good heat transfer between the layers more than once. However, the basalt fiber leads to enhanced thermal conductivity in composites.

4. Conclusions

The effect of Kevlar and basalt fiber on thermal adsorption, heat deflection temperature, coefficient of linear thermal expansion, and thermal conductivity of epoxy hybrid composite was studied experimentally, and their results were compared to obtain optimum properties. A low-cost conventional hand layup technique successfully fabricated the epoxy hybrid composite. Samples 3 and 4 of multilayer (KF/BF with epoxy) composites performed good thermal performance compared to the monolayer (KF and BF with epoxy) samples 1 and 2. Sample 4 (BF/KF/KF/BF) had an excellent thermal adsorption effect and a reduced mass loss during decomposition of 70.98%. Similarly, the heat deflection temperature and coefficient of linear thermal expansion are offered with basalt fiber at 69.23°C/Kg and 11.78×10^{-6} per °C. The multilayer sample 3 epoxy hybrid composite found good thermal conductivity, with a value of 0.251 W/mk, and has improved by 26.6% compared to sample 1. However, the basalt fiber-faced sample 4 epoxy hybrid composite observed good thermal adsorption behavior and limited mass loss with controlled decomposition with reduced heat deflection temperature acting as better insulation for heat energy storage applications in power plant sectors.

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. M. Christensen, *Mechanics of Composite Materials*, Courier Corporation, North Chelmsford', MA, 2012.

[2] P. K. Mallick, *Fiber-Reinforced Composites: Materials, Manufacturing, and Design*, CRC press, Boca Raton', FL, 2007.

[3] P. V. Straznicky, J. F. Laliberté, C. Poon, and A. Fahr, "Applications of fiber-metal laminates," *Polymer Composites*, vol. 21, no. 4, pp. 558–567, 2000.

[4] A. Elmarakbi, *Advanced Composite Materials for Automotive Applications: Structural Integrity and Crashworthiness*, John Wiley & Sons, Hoboken, NJ, USA, 2013.

[5] O. M. L. Asumani, R. G. Reid, and R. Paskaramoorthy, "The effects of alkali-silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites," *Part A Applied science manufacturing*, vol. 43, no. 9, pp. 1431–1440, 2012.

[6] G. R. Arpitha and B. Yogesha, "An overview on mechanical property evaluation of natural fiber reinforced polymers," *Material Today Proceeding*, vol. 4, no. 2, pp. 2755–2760, 2017.

[7] S. Biswas, S. Shahinur, M. Hasan, and Q. Ahsan, "Physical, mechanical and thermal properties of jute and bamboo fiber reinforced unidirectional epoxy composites," *Procedia Engineering*, vol. 105, pp. 933–939, 2015.

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

[9] M. Ramasamy, A. Arul Daniel, M. Nithya, S. Sathees Kumar, and R. Pugazhenthi, "Characterization of natural - Synthetic fiber reinforced epoxy based composite - Hybridization of kenaf fiber and kevlar fiber," *Materials Today: Proceedings*, vol. 37, pp. 1699–1705, 2021.

[10] A. Sarwar, Z. Mahboob, R. Zdero, and H. Bougherara, "Mechanical characterization of a new kevlar/flax/epoxy hybrid composite in a sandwich structure," *Polymer Testing*, vol. 90, article 106680, 2020.

[11] M. Bulut, "Mechanical characterization of basalt/epoxy composite laminates containing graphene nanopellets," *Composites Part B: Engineering*, vol. 122, pp. 71–78, 2017.

[12] S. Rajesh, B. V. Ramnath, C. Elanchezhian, M. Abhijith, R. D. Riju, and K. K. Kishan, "Investigation of tensile behavior of Kevlar composite," *Material today proceeding*, vol. 5, no. 1, pp. 1156–1161, 2018.

[13] C. Fragassa, A. Pavlovic, and C. Santulli, "Mechanical and impact characterisation of flax and basalt fibre vinylester composites and their hybrids," *Composites Part B: Engineering*, vol. 137, pp. 247–259, 2018.

[14] T. Behzad and M. Sain, "Measurement and prediction of thermal conductivity for hemp fiber reinforced composites," *Polymer Engineering and Science*, vol. 47, no. 7, pp. 977–983, 2007.

[15] 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.

[16] R. Venkatesh, N. Karthi, N. Kawin et al., "Synthesis and adsorbent performance of modified biochar with ag/MgO nanocomposites for heat storage application," *Adsorption Science & Technology*, vol. 2022, article 7423102, pp. 1–14, 2022.

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

[18] B. Schrauwen and T. Peijs, "Influence of matrix ductility and fibre architecture on the repeated impact response of glass-fibre-reinforced laminated composites," *Applied Composite Materials*, vol. 9, no. 6, pp. 331–352, 2002.

[19] M. Khazaie, R. Eslami-Farsani, and A. Saeedi, "Evaluation of repeated high velocity impact on polymer-based composites reinforced with basalt and Kevlar fibers," *Materials Today Communications*, vol. 17, pp. 76–81, 2018.

[20] R. D. Sweeting and X. L. Liu, "Measurement of thermal conductivity for fibre-reinforced composites," *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 7-8, pp. 933–938, 2004.

[21] Z. Javanbakht, W. Hall, and A. Öchsner, "Effective thermal conductivity of fiber reinforced composites under orientation clustering," *Advanced Structured Materials, Springer International Publishing*, vol. 92, pp. 507–519, 2019.

[22] C. Ramesh Kannan, R. Venkatesh, M. Vivekanandan et al., "Synthesis and characterization of mechanical properties of AA8014 + Si3N4/ ZrO2 hybrid composites by stir casting process," *Journal of Advances in Materials Science and Engineering*, vol. 2022, article 9150442, pp. 1–11, 2022.

[23] S. Ghasemi, M. Tajvidi, D. W. Bousfield, and D. J. Gardner, "Reinforcement of natural fiber yarns by cellulose nanomaterials: a multi-scale study," *Industrial Crops and Products*, vol. 111, pp. 471–481, 2018.

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

[25] 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.

[26] N. B. Karthik Babu, S. Muthukumaran, S. Arokiasamy, and T. Ramesh, "Thermal and mechanical behavior of the coir powder filled polyester micro-composites," *Journal of Natural Fibers*, vol. 17, no. 7, pp. 1058–1068, 2020.

[27] G. Mittal, K. Y. Rhee, V. Mišković-Stanković, and D. Hui, "Reinforcements in multi-scale polymer composites: processing, properties, and applications," *Composites Part B: Engineering*, vol. 138, pp. 122–139, 2018.

[28] 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.