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Research Article

Influences of Various Thermal Cyclic Behaviours on Thermo Adsorption/Mechanical Characteristics of Epoxy Composite Enriched with Basalt Fiber

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Exposure to advanced materials with unique thermomechanical characteristics has fulfilled the requirements of automotive, marine, and structural industries. The current research investigates the thermal adsorption and mechanical properties of epoxy composite enriched by basalt fiber via resin moulding technique with an applied pressure of 2 bar. Hydrophobic and dynamic analyzer tests developed composite's adsorption storage and loss modulus with 10, 30, 50, 70, 90, and 110 thermal cycles under 18°C to 150°C. ASTM test standards evaluated the effect of the thermal cyclic process on mechanical properties. The composite contained 45 vol% basalt fiber with 90 thermal cycles and found higher adsorption storage modulus, elasticity, tensile strength, and flexural strength of 9200 GPa, 80 GPa, 229 MPa, and 398 MPa, respectively. The thermal adsorption loss modulus was limited by 12% on 90 thermal cycles at 150°C compared to 10 thermal cycles.

1. Introduction

The utilization of polymer-based filler material was widely augmented in several applications due to their improved thermal stability, good mechanical characteristics, light weight, ability to make composite on compound phase, and durability [1–3]. The most common resin, epoxy, was bonded with different natural and synthetic fiber facilities with good mechanical and thermal characteristics [4–6]. Most researchers studied the performance of epoxy composite with natural fibers like jute fiber [7], aramid [8], basalt fiber [9], flax [10], glass, and carbon fiber [11] attained enhanced thermomechanical characteristics. Along with the different filler (natural fiber) materials mentioned above, basalt fiber has excellent chemical and thermal stability with superior tensile strength [12]. Additionally, it is ecofriendly during preparation and easy to recycle [13, 14]. The absorption capability of hybrid composite with aramid/basalt fiber was evaluated and its result showed increased impact energy of composite [15]. The degradation properties of tensile strength of basalt fiber-reinforced polymer and fiber-reinforced polymer tendons for marine environment was investigated and compared [16]. The thermal performance of epoxy-developed composite with various weight

(a) (b)

Figure 1: Main constitutions of epoxy composite (a) basalt fiber and (b) epoxy resin with hardener.

Table 1: Physical and mechanical properties of raw materials.

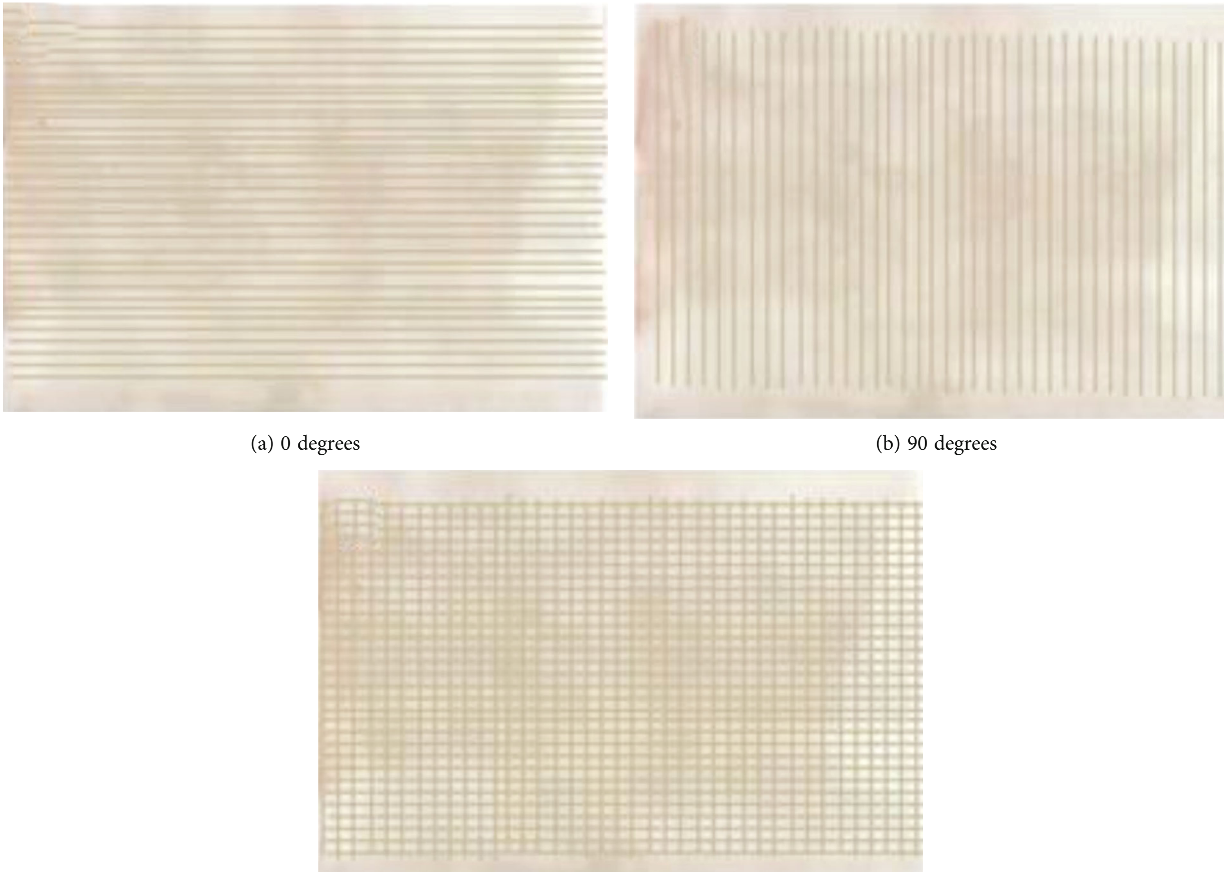
Materials/properties	Density (g/cc)	Elastic modulus (GPa)	Tensile strength (MPa)	Thermal conductivity (W/mK)	Coefficient of thermal expansion Per $^{\circ}C \times 10^{-6}$
Epoxy	1.131	3.30	92.7	0.6	66
Basalt fiber	2.12	64	4537	0.0331	6

percentages of multiwalled nanotubes and micro-SiC was studied. It revealed that the composite containing 6 wt% multiwalled nanotubes showed 2.9 times higher thermal conductivity than unreinforced epoxy [17]. The properties of epoxy composite have been resolute by the behaviour of chemical action between matrix and fiber [18]. The mechanical performance of basalt fiber and glass fiber reinforced polymer composite fabricated by hand layup technique and studied its mechanical behaviour. The composite result found that basalt and glass fiber showed similar mechanical performance on applied high mechanical force [19].

The E-glass fiber/multiwalled carbon nanotubes reinforced epoxy composite was developed and studied by their thermomechanical properties. The physical presence of both E-glass fiber and multiwalled carbon nanotubes in epoxy composite has higher thermomechanical characteristics [20, 21]. The mechanical properties of basalt fiber reinforced polymer composites instead of the glass fiber composite structure were examined by SEM. The composite results showed maximum bending and tensile strength compared to the existing glass fiber composite structure. The physical presences of basalt fiber content on epoxy composite have high thermal performance [22, 23]. Based on the literature listed above, the basalt fiber reinforced epoxy composite performs good thermomechanical characteristics compared to other fibers. So the present research investigation is to develop an epoxy composite containing 25 wt% of basalt fiber by resin mould technique. The developed composites are subjected to thermal adsorption and mechanical studies. The effect of thermal cycles on thermal adsorption storage modulus, modulus of elasticity, tensile strength, and flexural strength of the epoxy composite is tested by ASTM D3039 standards.

2. Materials and Method

2.1. Choice of Matrix and Reinforcement Materials. The epoxy resin and basalt fiber were chosen as the primary constitutions and reinforcement for the current research work. The epoxy resin is suitable for combination with nonreactive and reactive additives facilitating easy profile modification [24, 25]. Among the various fibers were referred from literature studies, basalt fiber has enhanced thermal and chemical stability, good tensile strength, and easy to recycle [12–14]. The basalt fiber and epoxy resin are illustrated in Figures 1(a) and 1(b). The physical and mechanical properties of both materials are detailed in Table 1.



(a) 0 degrees

(b) 90 degrees

(c) 2 × 2 texture design mat

Figure 2: The epoxy composite texture layup design pattern with different orientations (a) 0 degrees, (b) 90 degrees, and (c) 2 × 2 texture design mat.

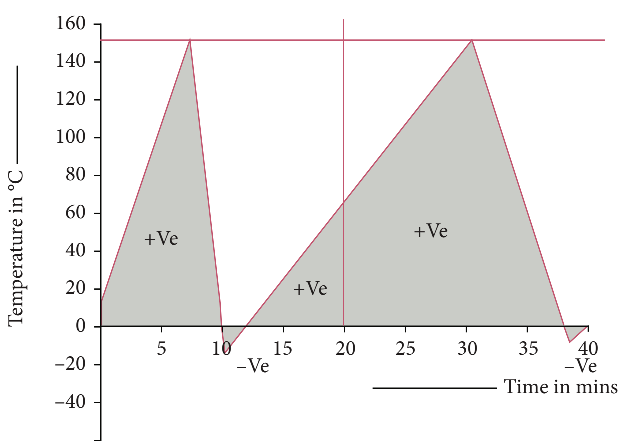


Figure 3: Thermal cyclic profile curve during various thermal cycles.

Table 2: Effect of damping factor and glass transition temperature effect on thermal adsorption of an epoxy composite.

Thermal cycle	d_{max}	GTT
10	0.3221	86.12
30	0.3144	86.21
50	0.3109	86.21
70	0.3094	86.23
90	0.3065	86.28
110	0.3038	86.29

2.2. Processing of Epoxy Composite. Initially, the actual length of basalt fiber is waving with epoxy resin for the orientations of 0° and 90° parallel 2 × 2 texture design pattern as shown in Figure 2. The 45 vol% of basalt fiber is structured by epoxy resin as 2 × 2 texture design via hand-operated autowaving tool attached with resin mold. Meantime, the 55 vol% of epoxy is collected from a resin container with the help of a vacuum pump with a pressure of 2×10^5pa, and then the collected epoxy is slowly layup on the above surface of 2 × 2 basalt mat, resulting in an even distribution of epoxy can able to make good interfacial bonding strength. Finally, bonded epoxy and basalt fiber layer is compacted with an applied pressure of 2 bar. The compressive force may enhance the interfacial bonding quality and resist the fiber movement between the interlayer during high tensile load. However various fabrication techniques are available for making PMC, but the resin mold technique is the most common and inexpensive method for developing PMC [24, 25]. Similarly, the second layer of epoxy composite is prepared and the final composite has a size of 100 × 100 × 3

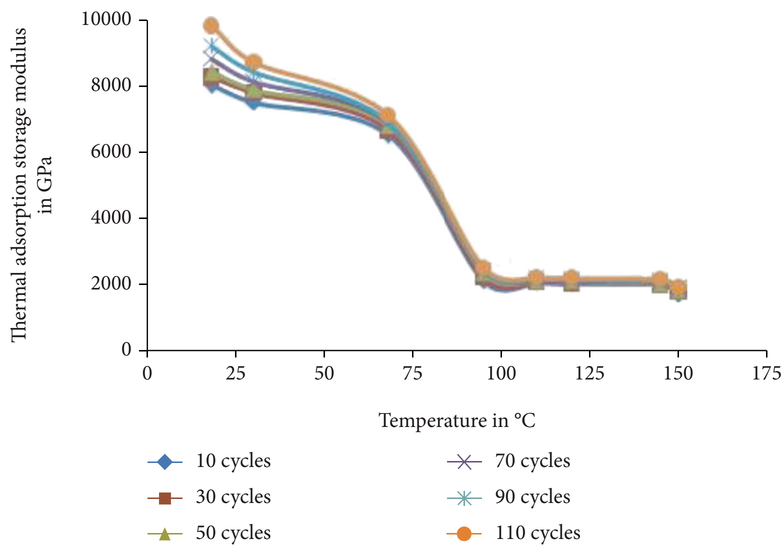


Figure 4: Thermal adsorption storage modulus of epoxy composites.

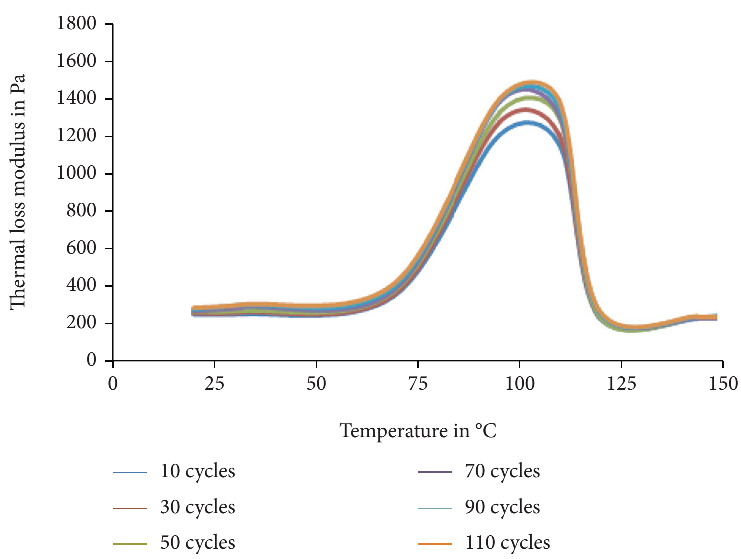


Figure 5: Thermal loss modulus of epoxy composites.

mm. The epoxy composite is shaped per ASTM test standards via a water jet machining process.

2.3. The Thermal Cyclic Design Process. It was considered different thermal cycle sequences of 10, 30, 50, 70, 90, and 110 cycles with increased temperatures of 18°C to 150°C. Then, it fell to -18°C. Each cycle has been defined with an interval sequence of 20 cycles; under the dwell time of 20 mins, thermal profile is shown in Figure 3. However, the cyclic thermal curve falls -18°C due to the solidification of basalt fiber after epoxy layup. The temperature was reduced to below the ambient temperature. It helps to increase the quality and a sufficient compact ratio is obtained during the final process. Similarly, the CFD technique observed the circular tube heat transfer with various thermal cycles [26].

3. Result and Discussions

3.1. Thermal Adsorption Storage Modulus. The Visco-Elastic thermal adsorption properties of the epoxy composite were evaluated by a dynamic analyzer with mechanical probe assembly. It was tested under the ASTM standard of D7028. The bonded structure of the epoxy composite was closely monitored into three different bending points on 1 Hz frequency at 18°C to 150° temperature under an applied load of 20 N associated with a 3°C/min heating rate.

The significance of glass transition temperature (GTT) and damping factor (dmax) for the epoxy composite was derived from digital analyzer trace points and its values were represented in Table 2. Figure 4 illustrates the Visco-Elastic thermal adsorption storage modulus of epoxy composite enriched with basalt fiber under different thermal cycles. It

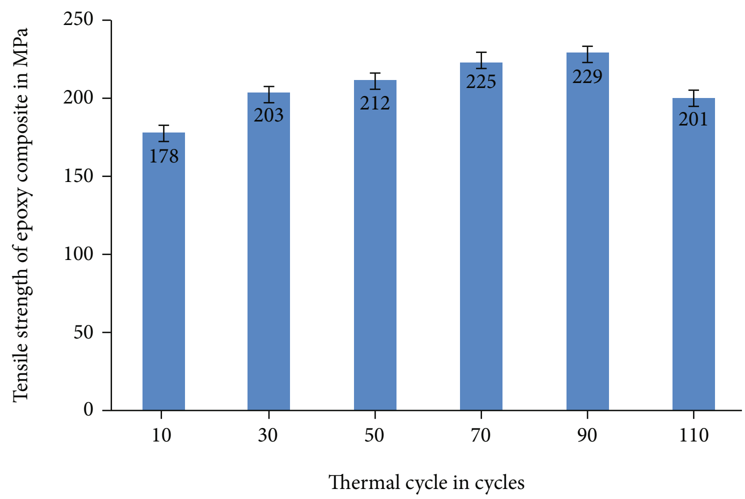


Figure 6: Tensile strength of epoxy composite with various thermal cycles.

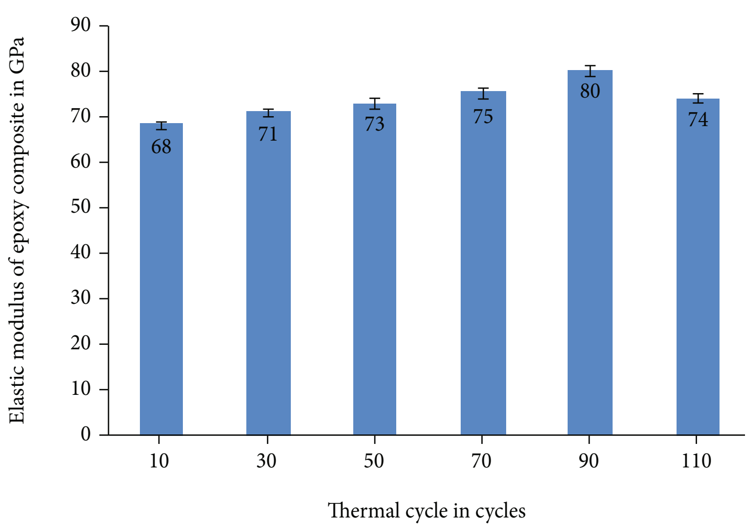


Figure 7: Elastic modulus of epoxy composite with various thermal cycles.

was noted from the above curve in Figure 4 that the thermal adsorption modulus of epoxy composites gradually decreased with an increase in temperature. But the composite that facilitates 110 cyles gained the maximum energy storage modulus of 9800 GPa. It was due to the glass transition temperature and cross-interface effect on a higher temperature. A similar trend was found in nylon copolymer/EPDM rubber [27].

3.2. The Thermal Loss Modulus of an Epoxy Composite. Figure 5 represents the thermal loss modulus of an epoxy composite containing 45 vol% of basalt fiber evaluated by different thermal cycles. The composite facilitates three stages: rubbery, glass, and glass transition state. The rubbery state has no significant changes in thermal adsorption storage and loss modulus [27]. In the glass stage, the composite's structure was controlled on the most significant thermal storage modulus [26, 28]. At the same time, the GTT state thermal storage modulus has decreased progressively on the sensitivity of temperature changes. So the GTT state has very important for deciding the properties of polymer composites.

As seen from Figure 5, the epoxy composite's thermal loss modulus gradually increased with temperature increase from 18°C to 75°C. Further increase in temperature showed the thermal loss modulus of composite has decreased. However, the thermal loss of epoxy composite may be varied due to the sensitivity of temperature, and a similar type of thermal profile was generated on various thermal cycles.

4. Mechanical Characteristics of Epoxy Composite on Different

4.1. Tensile Strength of Epoxy Composite. The tensile strength of the composite was evaluated by FIE make universal tensile machine with a capacity of 40 ton followed by ASTM D3039 standard with the dimensions of $250 \times 150 \times 25$ mm, respectively. Figure 6 shows the tensile strength of epoxy composite with 10, 30, 50, 70, 90, and 110 thermal cycles.

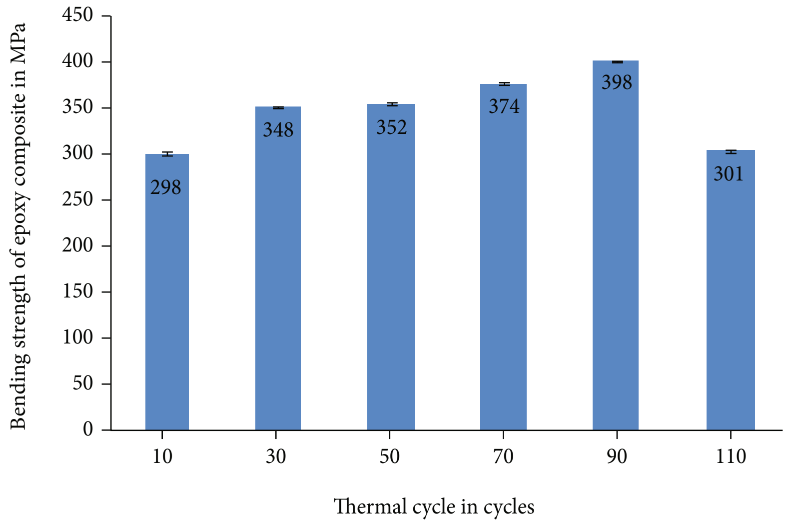


Figure 8: Bending strength of epoxy composite with different thermal cycles.

Figure 6 indicates basalt fiber's effect on the composite's tensile strength with varied thermal cyclic conditions. The tensile strength of the composite was gradually increased with the increase of the thermal cycle from 10 cyles to 90 cycles. Further increase in thermal cycle resulted in decreased tensile strength of 201 ± 2.1 MPa. It was due to the effect of thermal treatment and mismatched interlink connection of epoxy and basalt fiber. It was found that the composite has 90 thermal cycles and showed a maximum tensile strength of 229 ± 1.1 MPa. It increased by 28.65% as compared to 10 thermal cycles.

Similarly, the tensile strength of each cycle was increased by 14%, 19.1%, 26.4%, and 28.65%, respectively. It was because the effect of good chemical interface orientation on cyclic thermal action was insufficient to break. However, the treatment of thermal action may damage the polymer composite's chemical structure [9, 10].

4.2. Elastic Modulus of an Epoxy Composite. Figure 7 illustrates the modulus of elasticity of epoxy composite with different thermal cycles. The treatment of different thermal conditions was the most significant factor in improving mechanical properties. The epoxy composite's phenomenon was enhanced by the basalt fiber's orientation chemically bonded with resin resulting in high elastic modulus. It was observed from Figure 7 that the elastic modulus of the epoxy composite was progressively increased with increased thermal cycles of 90 nos.

The maximum elastic modulus of 80 GPa was identified as 90 thermal cycles. The characteristics investigation of the epoxy composite was enriched by basalt fiber act as superior strength at a higher temperature. However, further improvement in the thermal cycle of more than 90nos showed 74 GPa. It was due to the deviation of basalt fiber from resin.

4.3. Bending Strength of Epoxy Composite. The bending strength of epoxy composite with different thermal cyclic conditions is represented in Figure 8. It was increased 298 ± 2.1 MPa, 348 ± 0.91 MPa, 352 ± 3.2 MPa, $374 \pm 1.8\,MPa$, and 398 ± 0.71 MPa on 10, 30, 50, 70, and 90 thermal cycles. After 90 cycles, it reached 301 MPa due to the postcuring effect of strength between epoxy and basalt fiber. However, basalt fiber owed high thermal stability [12–14, 22]. The higher bending strength of $398 \pm 0.71\,MPa$ was observed in 90 cyles can withstand the higher temperature of 150°C. It was due to their highly effective bonding between epoxy and fiber, leading to resisting the high bending load without fracture or bulge of composite. The higher temperature was insufficient to damage the epoxy composite's chemical bonding [18, 27, 28].

5. Conclusions

The resin mould technique successfully developed the epoxy composite with an applied pressure of 2 bar. The mechanical properties like tensile, elastic modulus, and bending strength of composites were enriched by basalt fiber. A dynamic analyzer with a mechanical probe point investigated the effect of 10, 30, 50, 70, 90, and 110 cyclic thermal behaviour on thermal adsorption storage and loss modulus of the developed composite. The following results were made from the present research are mentioned below.

(1) The effect of thermal cycles on thermoadsorption/mechanical characteristics of epoxy composite found superior thermal adsorption with high tensile and bending strength

(2) The composite contained 45 vol% of basalt fiber resulting in a higher thermal adsorption storage modulus of 9200 GPa under 150°C with a good glass transition temperature effect on 90 cycles

(3) Similarly, the epoxy composite's overall thermal adsorption loss modulus was limited by 12% on 150°C operated under 90 thermal cycles compared to 10 cycles

(4) Composite with 90 thermal cycles was found to have a superior tensile strength of 28.65% improvement compared to 10 cycles. Similarly, the bending strength of the composite showed 398 ± 0.71 MPa

(5) The elastic modulus of epoxy composite was estimated with different sequence thermal cycles, showing the parallel improvement and 90 cycles having a better elastic modulus of 80GPa. So, that epoxy composite with basalt fiber has good thermal adsorption modulus and superior mechanical properties

(6) The transportation of rooftop structure application utilized the superior properties of a developed best sample of the epoxy composite

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.

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