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# PERFORMANCE EVALUATION OF VARIOUS NATURAL FIBRE-REINFORCED HYBRID POLYMER COMPOSITES FOR ENGINEERING APPLICATIONS

**Summary**

In recent materials science developments, composite materials are emerging as a sustainable alternative to conventional materials. Addressing the issue of annual disposal of three to four million tons of biological waste, particularly hair fibre in India, a reinforced polymer composite has been created by combining this waste with resins. Using a hand lay-up technique and constant load, a hybrid composite of Kevlar (K29) and Human hair fibre was formed, reinforced separately with Epoxy resin-556, Polyester, and Polyvinyl chloride ( PVC) separately. Conversion to ASTM standard samples allowed for an analysis using scanning electron microscopy (SEM), which revealed that the epoxy-reinforced hybrid composite exhibits high tensile strength, making it suitable for automotive parts manufacturing. While polyester and PVC-reinforced composites have advantages such as cost-effectiveness and corrosion resistance, they generally exhibit inferior mechanical properties compared to epoxy resin-reinforced composites. Epoxy resin composites are often preferred for applications where superior mechanical performance is required, albeit at a higher cost. This study not only promotes sustainability by repurposing biological waste but also demonstrates the versatility of composites in meeting diverse industrial requirements.

*Key words:* *hybrid composites, polymer matrix, tensile strength, engineering applications*

## 1. Introduction

Kevlar, a strong and heat-resistant synthetic fibre, exhibits a remarkable strength-to-weight ratio and is about five times stronger than steel. Widely used in applications such as bulletproof vests, bicycle tires, and racing sails, Kevlar's versatility extends to high-impact uses, including modern marching drumheads [1]. The synthesis process involves a condensation reaction, yielding Kevlar and hydrochloric acid as a by product. The more layers of Kevlar fibres the higher the product cost [2]. A lower percentage of Kevlar reinforced with natural fibres results in higher mechanical strength at a low cost [3]. Animal fibres, including hair, wool, and silk, are investigated as reinforcements in composites for unique properties, such as slow degradation, high tensile strength, and thermal insulation [4]. Human hair, with its hierarchical structure, is manipulated into mats with structural additives, offering versatile applications due to its scaly surface and interactions with water and oils [5]. In hair fibre-reinforced concrete, various percentages of human hair enhance tensile and compressive strength, binding properties, and spalling resistance, leading to a sustainable advantage. However, the widespread disposal of human hair raises ecological concerns despite its potential in biomedical applications for tissue regeneration and nanomedicine [6].

Epoxy resins, the key thermosetting polymers, find widespread use as protective coatings, structural adhesives, and matrix resins in fibre-reinforced composites [7]. Despite higher costs compared to the alternatives such as polyester or vinyl ester resins, epoxies offer superior mechanical properties and resistance to moisture and corrosive environments. Their durability results in a favourable cost-performance ratio, making them essential in industries such as construction, aerospace, and automotive [8]. Adhesive strength and low moisture absorption of epoxies make them ideal for bonding and protection against wear and corrosion. In general, due to their versatility and performance they are frequently used in high-performance applications [9]. Polymers, especially PVC, have replaced metals in various applications due to their cost-effectiveness and ease of processing. However, safety and environmental concerns arise with the use of PVC, including health risks associated with vinyl chloride and environmental damage during processing. To address these issues, blending PVC with natural fibres is explored as an eco-friendly alternative, balancing advantages and disadvantages. This approach not only improves mechanical properties but also aligns with environmental goals by offering carbon-neutral properties and lower abrasiveness compared to traditional reinforcements. The paper discusses the potential of PVC as a natural fibre composite matrix and strategies to improve the mechanical performance of these composites [10]. Natural fibres such as hemp, jute, banana, and others have been used to reinforce polyester composites. However, these fibres are prone to water absorption in humid conditions. Surface chemical modification has been explored to improve interfacial properties and reduce water absorption. Research dealt with adhesion quality, emphasising the impact of plant fibre length and content on mechanical properties [11]. The research focuses on evaluating the performance of composites by reinforcing Kevlar with human hair and various polymers i.e. epoxy resin, PVC, and polyester. These engineered composites aim to meet the requirements of diverse engineering applications, assessing factors such as strength, durability, and suitability for practical use. The combination of Kevlar and human hair with different polymer matrices presents a novel approach to creating advanced materials with potential applications in various engineering fields.

## 2. Selection of materials and Manufacturing methods

In the development of this composite material, the base components of Kevlar 29 woven fabric and human hair fibres were chosen as a strategic combination. The Kevlar fabric, sourced from Green India Ltd., contributes to the exceptional tensile strength and toughness, making it suitable for applications requiring resistance to impact and abrasion. Human hair fibres, procured from Hair Salon India, underwent an alkaline (acetone) treatment to eliminate impurities and moisture, followed by drying in the sun. Each bundle of human hair fibres measures 500 mm in length and 2 mm in width. For the resin matrix, epoxy resin Ly556, known for its superior adhesion, chemical resistance, and mechanical properties, was selected, accompanied by the hardener Hy 951 [12]. Additionally, polyester resin and polyvinyl chloride resin were employed to fabricate two other samples. This meticulous selection and the treatment process aim to harness the unique properties of each component, creating a composite material with properties tailored to specific applications [13].

The human fibre-reinforced composites were meticulously crafted using the hand lay-up technique [14]. A smooth, plain surface was selected as the foundation, and a layer of grease was applied to facilitate the release of the composite after the manufacturing process. To contain the resin and prevent leakage, a rectangular frame measuring 12 mm in thickness and 12 mm in height was formed around the fabrication area, creating a 500 x 300 mm frame. Three distinct samples were prepared, each employing a different resin matrix, i.e. epoxy resin, polyester or polyvinyl chloride. The top and bottom layers of all samples featured Kevlar 29 woven fabric, while the intermediate layer consisted of bundles of human hair fibres arranged in a vertical direction with a 2 mm gap between the bundles. The binding agents varied among the samples, with one using epoxy resin and a hardener, another employing polyester resin, and the third utilizing polyvinyl chloride resin. Following the layer formation, a constant load was applied to the fabricated composites for a day. Subsequently, the three samples (4.5 mm thick) named Sample 1 (Kevlar human hair epoxy (KHE) composite), Sample 2 (Kevlar human hair polyester composite (KHP) composite), and Sample 3 (Kevlar human hair PVC (KHPVC) composite), were carefully cut into specimens (five specimens were taken from each sample and tested for average strength) according to ASTM standards. Fig. 1 illustrates the detailed manufacturing method of the Kevlar-human hair-reinforced resin matrix composites.


**Fig. 1** Manufacturing method animal fibre reinforced composites (a. Grease coating, b. Epoxy coating, c. Vertically-oriented fibres, d. PVC layer formation, e. Polyester resin formation, f. Final layer of Kevlar fibre, g. Constand load applied over the composite, h. Final samples of composites, i. Alkaline treatment human hair fibre, j. Resins, and other components for fabrication).

## 3. Experimental Testing

An Instron series IX/S version 8.33 automated testing machine was employed to assess the mechanical properties of samples by the ASTM D3039 standard [15]. The tests were conducted at a constant rate of 10 mm/min with a maximum load of 10 kN while maintaining a humidity of 50% and a temperature of 73°F. Each sample was divided into five specimens following the ASTM guidelines, and the specimens were individually tested, with the average value being recorded as the final result. Impact resistance was measured based on the ASTM D256 standard. To evaluate the property of water resistance, three different samples were immersed in water for 30 days, and their weights were randomly checked throughout the period, adhering to the ASTM D570 standard. The thermal stability was measured by conducting the heat deflection test of the ASTM D648 standard. Both the micro structural analysis and the assessment of fibre orientation and layer formation were conducted using SEM. The results obtained from these comprehensive testing procedures provide valuable insights into the overall quality and performance of the tested composites [16].

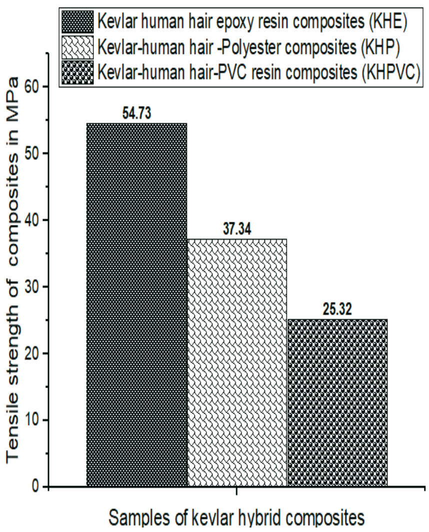
## 4. Result and Discussion

The study investigates the tensile and impact properties of composites composed of Kevlar human hair fibres reinforced with epoxy resin, polyester resin, and PVC resin matrices. The results, as presented in Table 1 and graphically depicted in Fig. 2. reveal distinctive characteristics of the three composites. Notably, the epoxy resin-reinforced Kevlar human hair (KHE) composite exhibited the highest tensile strength at 54.73 MPa, making it a robust candidate for applications where superior strength is crucial. However, the epoxy resin matrix is known both for its high cost and its superior viscous elastic properties during the curing process, good adhesion, low shrinkage, and non-toxic nature. In contrast, the polyester resin-reinforced Kevlar human hair (KHP) composite demonstrated a balance between mechanical properties and cost-effectiveness, boasting a tensile strength of 37.34 MPa, high moisture resistance, and durability.

**Table 1** Tensile and Impact strength of resins matrix composites

| Fabricated Composites | Tensile strength (MPa) | Elongation at break (%) | Tensile modulus (MPa) | Impact Strength (kJ/m$^2$) |
|---|---|---|---|---|
| Kevlar human hair epoxy composite (KHE) | 54.73 ± 0.8 | 5.3 ± 5.5 | 2473 ± 0.18 | 11.03 ± 0.7 |
| Kevlar human hair polyester composite (KHP) | 37.34 ± 1 | 4 ± 5.5 | 2033 ± 2 | 8.97 ± 1.2 |
| Kevlar human hair PVC composite (KHPVC) | 25.32 ± 0.6 | 3.6 ± 4 | 1872 ± 0.8 | 7.30 ± 1 |

The polyvinyl chloride resin-reinforced composite (KHPVC) exhibited the lowest tensile strength at 25.32 MPa and diminished impact resistance (7.30 kJ/m²). Despite being less expensive, PVC resin is characterized by lower tensile and impact strength, heightened shrinkage (5 to 12%) during fabrication, and suitability for chemical-resistant applications, such as roofing materials.



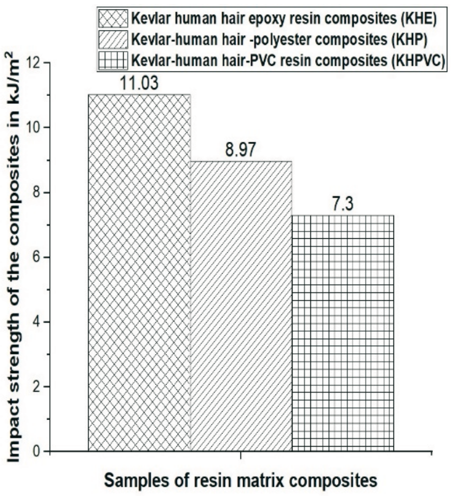




**Fig. 2** Tensile and impact strength of the composites

Impact resistance values for epoxy resin, polyester resin, and PVC resin are 11.03 kJ/m², 8.97 kJ/m², and 7.30 kJ/m², respectively. Fig 3. shows the heat resistance performance of resin matrix composites. Comparatively epoxy resin-reinforced Kevlar human hair composite has a high resistance of 85°C.

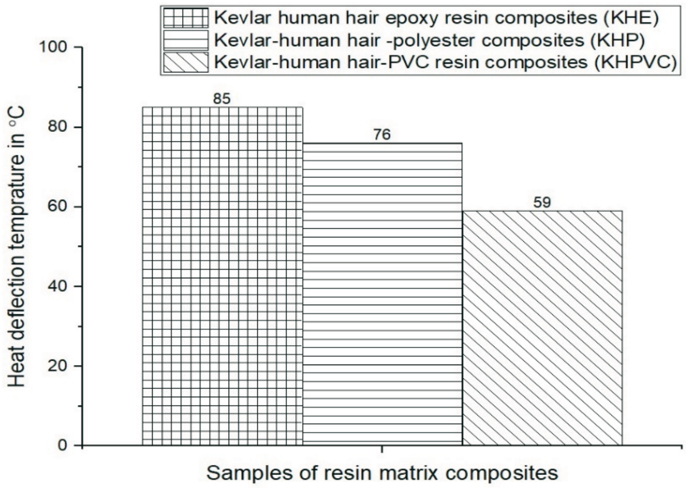



**Fig. 3** Heat deflection temperature of resin matrix composites

The study offers valuable insights into the diverse properties of these composites, aiding in informed material selection for specific applications based on a nuanced balance between performance attributes and cost considerations [17].

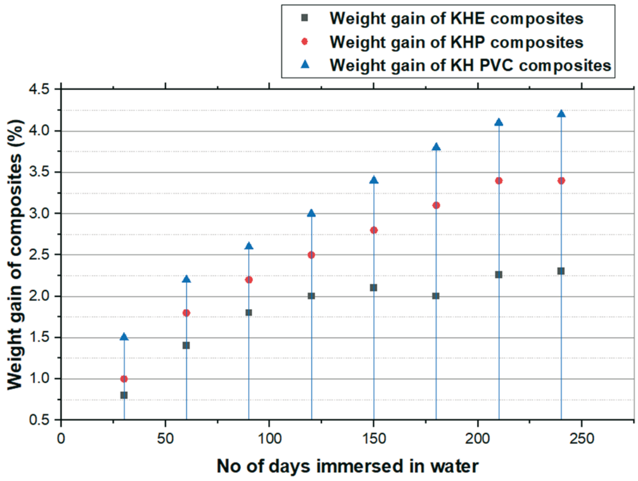



**Fig. 4** Water absorption of composites

The water resistance of three resin-reinforced human hair Kevlar fibre composites (Epoxy, Polyester, and PVC) was investigated following ASTM D 570 Standard. Each composite was immersed in groundwater individually, and their weights were checked periodically. Subsequently, the water absorption characteristics were monitored for nearly 240 days [18]. Results indicate that the Polyester resin-reinforced composite displayed comparatively lower water absorption, while the Epoxy resin-reinforced composite exhibited superior water resistance. Conversely, the PVC resin-reinforced composite showed higher water absorption, attributed to the specific characteristics of the incorporated fibre resin reinforcement. Water absorption percentages were calculated using the water-gained method. The extended monitoring period allowed for a comprehensive assessment of long-term water resistance. Fig 4. Shows and provides insights into the distinct water resistance performances of Epoxy, Polyester, and PVC resin-reinforced composites, offering valuable information for material selection in applications requiring optimal water resistance [19]. Fig 3. shows the heat deflection temperature of the resin matrix composite. Comparatively, epoxy resin matrix reinforced human hair Kevlar composite has high heat resistance [20]. The fracture surface scanning electron microscopy (SEM) images, captured at 100X and 200X magnifications, offer insightful observations into the microstructural characteristics of resin matrix-reinforced composites with Kevlar human hair [21].

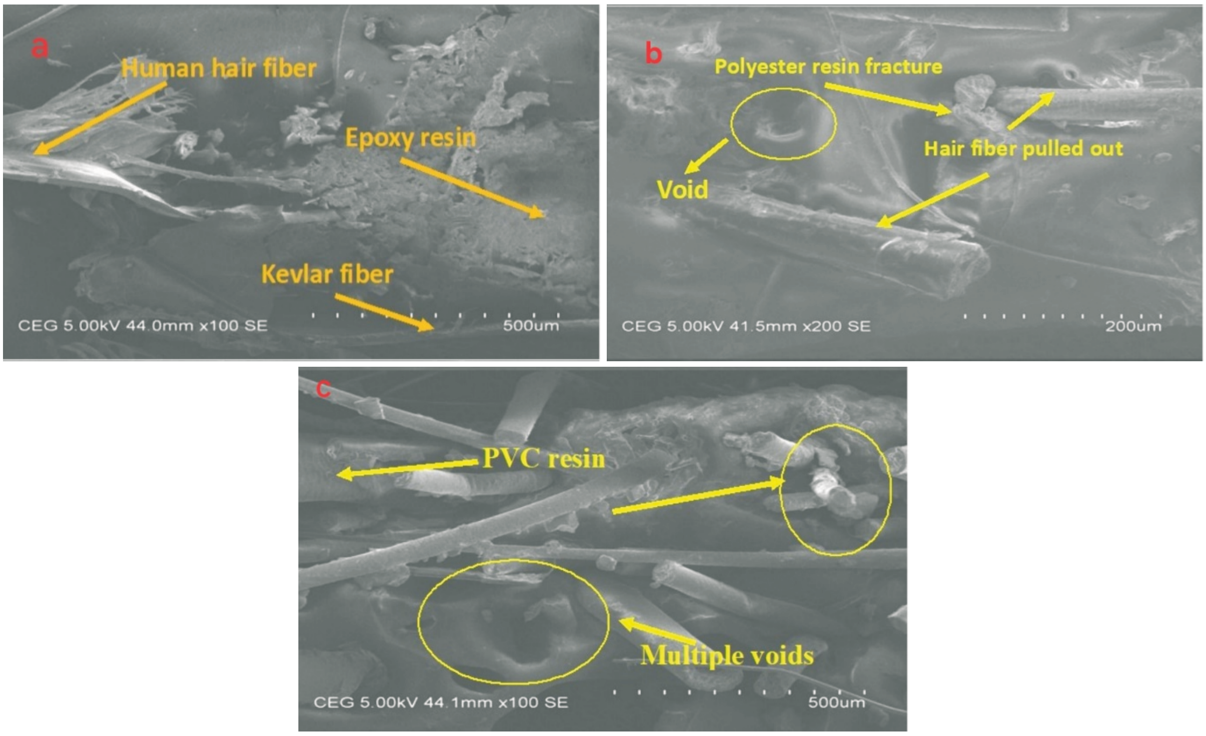



**Fig. 5** SEM images of resin matrix composites

In Fig.5a, the epoxy resin matrix composite exhibits commendable adhesion strength between fibres, accompanied by lower shrinkage and an absence of void formation. Notably, there is no evidence of fibre pull-out. In contrast, fig.5b showcases the polyester resin matrix composite, demonstrating improved adhesion to fibres compared to PVC resin. However, some fibres are observed to be pulled out. Fig.5c reveals the PVC resin matrix composites, indicating a deficiency in adhesion between the resin and fibres, along with the presence of multiple voids and significant fibre pull-out. This characteristic damage is identified as a factor influencing the mechanical properties of the composites. In conclusion, the comparative analysis underscores the superiority of epoxy resin-reinforced Kevlar human hair composites in terms of microstructural properties. These findings suggest its suitability for applications demanding higher mechanical properties, such as the production of electrical resistance panels [20].

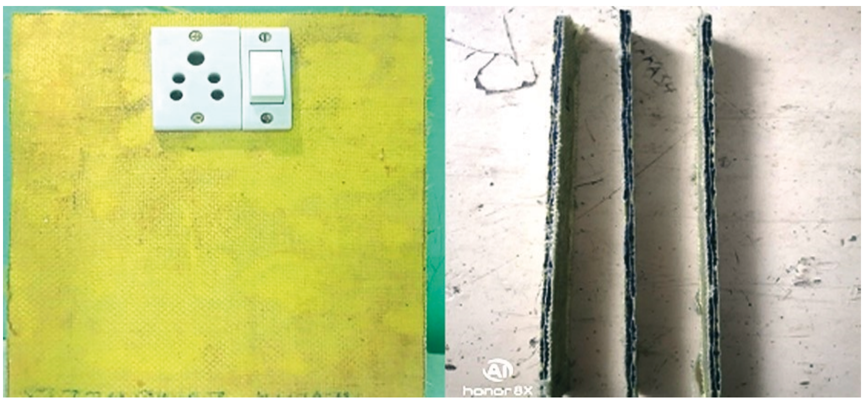


**Fig. 6** Electrical board and automotive door panel application of composites

Fig 6. depicts an electrical switchboard fabricated from an epoxy resin-reinforced Kevlar and human hair composite, specifically engineered for applications in marine construction. Fig 6. Shows lining materials made from epoxy resin matrix composite and these composite exhibits remarkable attributes such as high thermal and electrical resistance, making it well-suited for the demanding conditions prevalent in marine environments. The polyester-reinforced composite, renowned for its elevated electrical resistivity and heat deflection capabilities, finds its niche in the manufacturing of printed circuit boards. This material choice ensures the reliability and efficiency required in electronic applications. On a different note, a PVC resin matrix composite is employed in biomedical applications, particularly for textile materials and patient-aided accessories. The unique properties of this composite make it a suitable candidate for use in the medical field, catering to the diverse needs of healthcare applications. Overall, the strategic selection of composite materials based on their distinct characteristics underscores their significance in addressing specific requirements across various industries [22].

## 5. Conclusion

The study delved into investigating the mechanical and thermal properties of composite materials reinforced with Kevlar and human hair fibres, utilizing epoxy, polyester, and PVC resin matrices. It found that the Kevlar human hair-epoxy resin composite (KHE Composite) exhibited superior tensile and impact strength compared to epoxy and PVC resin composites, with additional benefits like enhanced water resistance and thermal stability due to the layering of Kevlar fibres. Among the combinations studied, the Epoxy resin matrix Kevlar human hair-reinforced composite (KHE composite) showcased the best mechanical properties, boasting a tensile strength of 54.3 MPa and an impact strength of 11.03 kJ/m$^2$, along with good thermal stability up to 85°C. While the Polyester resin-reinforced Kevlar human hair composite (KHPV composites) displayed satisfactory mechanical properties, they were inferior to the other composites. Overall, the study concluded that blending Kevlar and human hair fibre with various polymer matrices significantly enhances mechanical properties, makes cost-effective options suitable for diverse engineering applications.

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