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Influence of natural fibers on mechanical, thermal, water absorption and morphological characteristics of Kevlar Hybrid Epoxy composites for shipbuilding application

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The present work investigated the influence of natural fibers in Kevlar-reinforced epoxy composite. In this research, four layers of Kevlar woven fiber are fabricated by hand layup technique. In each sample, three layers of natural filler are filled between the Kevlar fabric layer. Three samples are fabricated, and each sample is added either with eggshell powder, Banana Bract, Human hair, which is reinforced with epoxy resin 10:1 ratio. The characterization of mechanical and thermal behavior evaluated by tensile, flexural, thermal conductivity, heat deflection, and water absorption is analyzed by ASTM standards. Mechanical fractured surface and interfacial adhesion layer formation are analyzed in Scanning electron microscopy. The result shows that eggshell powder-filled Kevlar epoxy composite exhibits higher mechanical properties than the other two epoxy composite filled with either human hair or banana bract. Human hair-filled Kevlar composite had better mechanical properties than banana bract composite. The study of the morphological structure shows that Eggshells and human hair-filled composite have less water absorption, high heat resistance, low thermal conductivity. This fabricated composite can be utilized for ship fuel tank covers, valve covers, lining materials of marine constructions.

Keywords: Kevlar composite, Thermal characteristics, Morphological analysis, Shipbuilding applications

1 Introduction

Nowadays, most researchers are focusing on fiber-reinforced polymer composite due to its high material properties. The FRP composite has achieved effective and reliable lightweight structure and non-corrosion, less water absorption, high strength, and weight ratio. Natural fiber possesses higher physical-mechanical properties but is not suitable for load-bearing application. Fiber-reinforced polymer matrix developed the adhesion between fibers and served as better structural properties[1-7]. In the marine environment, polymer-based composite is utilized to construct bulkheads, propeller shafts, ship hulls, building boats, durable vessels, weight reduction, joining, and reducing parts count[8-10].Carbon and Kevlar fiber reinforced matrix are mostly used in marine construction, and recently GRP composite is utilized. Kevlar matrix hybrid composite has higher mechanical properties, better heat, and water resistance[11-15]. Shipbuilding structure involved under cyclic loading environment; fatigue characteristics predict the lifetime of the polymer reinforced composite. Continuous loading of FRP composite creates matrix cracking, interlaminar delamination, and fiber fracture. Present designers, before selecting materials, usually consider the fatigue characteristics to prevent failure. Combining natural and polymer materials, resin matrix rein for cement decides the fatigue behavior and mechanical characteristics[16-20]. Globally hen eggshell wastage from food processing is estimated to be metric tons per year. The eggshell Chemical composition with 95% Calcium carbonate present has high thermal stability with pore structure. The eggshell powder used as filler between natural and polymer reinforced epoxy resin matrix gives higher mechanical properties and high heat resistance and can be used for automobile parts productions[21-24]. Human hair has a complicated multi-scale structure and non-degradable property. Cortex is a structural element of human hair and has a complex polymer structure, which plays a significant role in mechanical

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properties. Chemical treatment of human hair decreased its mechanical properties, andthermal treatment improved its morphological properties. Animal fibers reinforced epoxy hybrid composite had higher mechanical properties, less absorption, high sensorial property, high friction efficiency, and fewer aquatic vibrations. Hair is used as filler in concrete and is utilized for various structural applications[25-31]. Banana fiber had better properties than other natural fibers. Banana bract, banana fiber reinforcement of epoxy hybrid composite, has high thermal stability for petrochemical plastic in the environment[32-35]. This research focuses on bio and non-degradable waste used as filler, and non-fillerin Kevlar epoxy composite; mechanical and thermal characteristics were studied and utilized for shipbuilding construction materials applications.

2 Methods and Materials

2.1 Materials

A strong Kevlar woven fabric was supplied by Go green Product. Pvt. Ltd, India, Eggshells were collected from the food processing unit in a hostel mess, immersed in NaOH solution, dried out in sunlight after a few hours, then crushed as a powder with 100µmsize. Human hair was purchased from a barbershop in India. The human hair, 30 cm long and 0.18 mm in diameter, was washed in acetone and dried out at atmospheric temperature. Finally formed a bidirectional mat of 30cm x 30 cm, each bundle with 2 mm thickness. Banana spathe collected by banana cultivation place in India. The banana bract fiberwas treated in NaOH solution and then fabricated to a square mat of 30 cm long and 5mm in width. HerenbaCo..Ltd. India supplied the epoxy matrix chosen Ly556 resin and Hy951 hardener.

2.2 Method of Manufacturing

The Kevlar epoxy hybrid composite fabrication is done by hand layup technique[14]. A smooth, clean mosaic tile surface was chosen (500 mm x 500 mm, 10mm thick), over the layer crease was applied to remove the composite after the manufacturing process. The square (302mm x 302mm, 3mm thick) cast-ironframe isplaced along the border around the molding area to prevent leakage of resin and fiber deformations. There were three samples prepared, each Kevlar woven cross fabric as the base material because it enhanced better mechanical properties of composites[27]. Three samples of top, bottom, and middle layers were formed with Kevlar woven fiber piles. Between Kevlar layers, the eggshell powder was filled, bidirectional human hair fiber mat, bidirectional banana bract fiber with epoxy resin, and hardener matrix. Sample 1 was prepared by mixing resin-hardener with filler eggshell powder, then stirred for five minis at 80 rpm. Finally, a homogeneous matrix and filler were obtained. A layer of mixture coated between Kevlar fiber. Sample 2 and Sample 3 were fabricated layer by layer formation with epoxy resin- hardener (10:1 ratio) matrix and filled human hair fiber mat, and woven banana bract fiber, respectively. Finally, three samples (300mm x300 mm and 4 mm thickness) manufactured were named Sample1-KE, Sample2-KH, Sample3-KB composite, and cut into specimens per ASTM standard. Fig. 1 shows the manufacturing method of Kevlar-based epoxy hybrid composites.

2.3 Experimental testing Method of Composites

UTES-60 Universal tensile testing machine was used to conduct tensile test ASTM D 30309 standard at room temperature and ambient pressure. Each sample with five rectangular bar specimens was tested and evaluated to obtain anaverage value. The test was done at Revaphoenixmetrology, India[20]. A three-point bending flexural test was done according to the ASTM D790 standard at CIPET, India. The test was conducted in a universal testing machine, crosshead speed of 2mm/min and 70 F, 40% Humidity. The average value evaluated from three samples showed higher flexural properties composite[28]. The heat deflection temperature was measured by HDT apparatus (CIPET, India) according to ASTM D648 standard, with loading pressure 1.8 MPa and temperature rising to 2 °C/min. The test result is obtained based on the average value of five specimens from each sample. The thermal conductivity of the composites is measured through a heat flow meter (CIPET, India) as per ASTM E 1350 standard. The temperature difference between plates is measured using a heat flux sensor[36,37]. The water absorption test is done in the ASTM D 570 standard. The specimens were immersed in different waters,their weight was checked atregular intervals, and the water-resistant properties were evaluated[38],[39]. The manufactured composite morphological structure, interlamination, layer formation, fiber presencearecharacterized by a Scanning electron microscope[40].

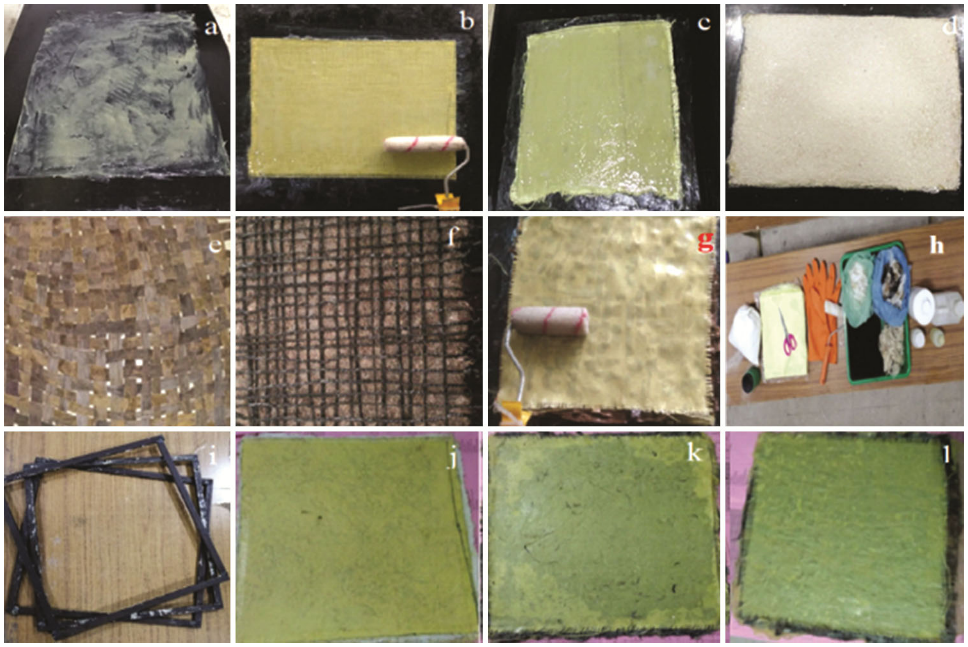

Fig. 1 — Fabrication of composites.

3 Result and Discussion

The manufactured composites were characterized based on various characteristics, and their results are discussed below.

3.1 Tensile strength

The ultimate tensile strength was developed for the current composite shown in Fig. 2.In the case of KE composite (sample 1), the tensile strength is 90 MPa. The KE composite, when compared with KH and KB, showed good adhesion properties. The bonding between eggshell filler and Kevlar epoxy composite was good due to the fine size of the filler, resulting in higher tensile strength. Now the comparison between KH and KB composites shows that KH has better tensile strength than KB composite.KH composite inter bonding between hairKH composite had better tensile strength than KB composite.KH composite inter-bonding between hair fiber and Kevlar epoxy composite created a dispersive structure after the test.In KB composite, banana bract had coarse size and low adhesion between Kevlar epoxy composite. Fig. 3shows the stress and strain relation between developed composites, where the composites exhibited a linear relationship[14,41].

3.2 Flexural Properties

Fig. 4 Shows the ultimate flexural strength developed for all three composites, namely eggshell filler, human hair, and banana bract. The flexural strength for KE, KH, KB composite was

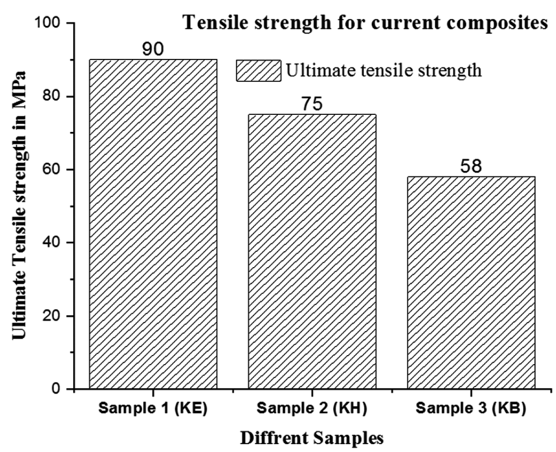

Fig. 2 — Tensile strength of non-filler and filler composites.

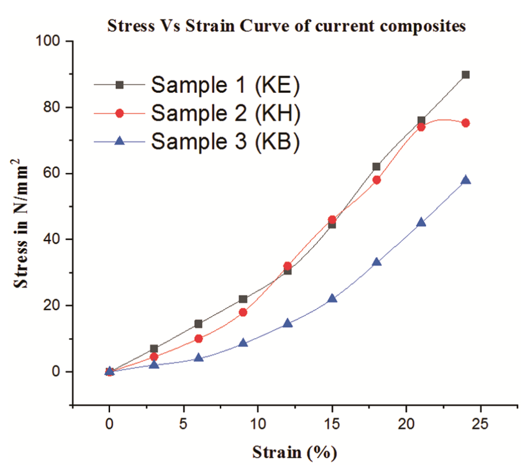

Fig. 3 — Stress Vs Strain Curve of composites.

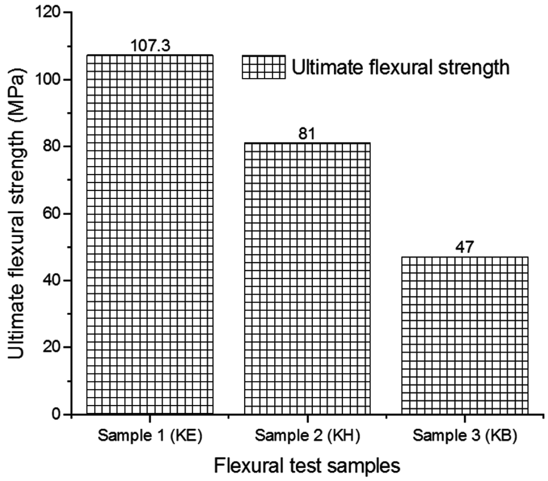

Fig. 4 — Ultimate flexural strength of composites.

107.3MPa,81 MPa, and 47 MPa, respectively. The KE composite had higher flexural strength among the other composites due to good fiber-matrix bonding, higher bending, and high deflection.KH composite has better flexural strength due to inner fiber orientation and interlocking of the fiber between human hair and Kevlar fabric. KB composite has less flexural strength than theother two due to poor adhesion between fiber matrix, which hascoarse structure[11,28].

3.3 Impact Strength

The impact force determines the toughness of the composite materials. The impact strength of the developed current composites is shown in Fig. 5. The KE composite has higher impact strength than the others due to filler and epoxy matrix, which exhibit good bonding in the interfacial region.KH composite produced better impact strength compared to the other two. Hair fiber having high elasticity and flexural properties absorbs more energy during impact testing. The KB composite has less impact strength due to banana bract having coarse and rough structures. Finally, it is concluded that eggshell filler reinforced epoxy composite produced higher impact strength[11,42].

3.4 Heat deflection test Analysis

The heat deflection Temperature test determined the polymer composites' resistance to distortion under a given 1.8MPa load at elevated temperature is shown in Fig. 6. The KH composite was enhanced at a higher temperature of 83℃due to the coarse structure and bonding matrix of eggshell filler. KB composite had better thermal stability at 77.5˚C. Compared to KB and KH composites, the strength of KE composite was the had less thermal stability because filler weight percentage changed thermal deformation.

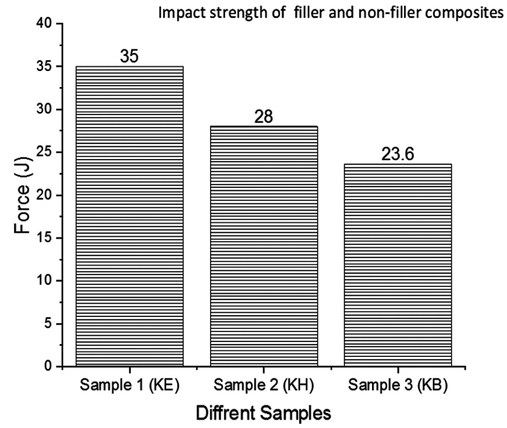

Fig. 5 — Impact strength of composites.

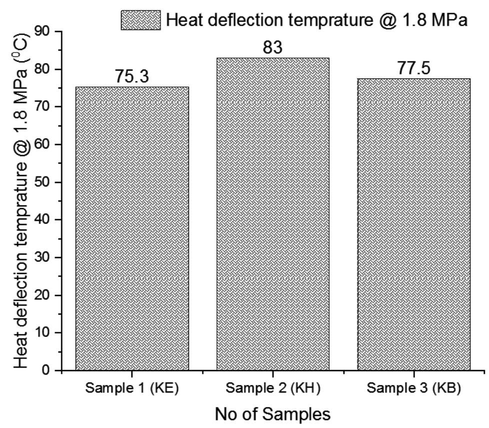

Fig. 6 — Heat deflection temperature of composites.

Nonfiller composite had a cross-linked polymer structure that may improve composites' thermal resistance[36].

3.5 Thermal conductivity

The thermal conductivity of polymer composite is the function of the thermal conductivities of filler and matrix. The volume of filler and polymer blockchains decides the thermal conductivity.The thermal conductivity of Kevlar hybrid epoxy composite is shown in Fig. 7. All the (KE, KH, KB) composites had less thermal conductivity due to less heat transfer. The KE composite has higher thermal conductivity than others. These low thermal conductivity composites are used as insulating materials in electrical and electronics applications[37].

3.6 Water Absorption Test

A water absorption test was performed in ASTM 570 standards. There were three types of water (distilled water, saltwater, seawater) used to immerse composites under ambient temperature. Fig. 8. shows

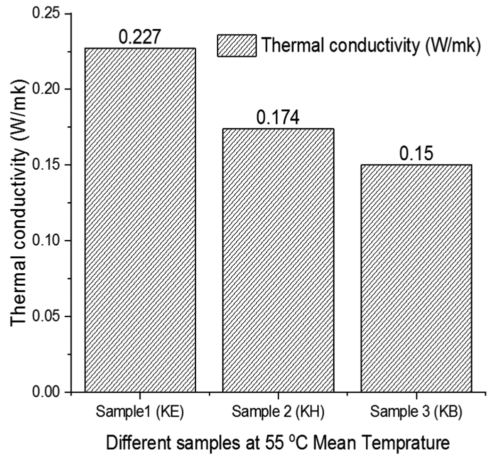

Fig. 7 — Thermal conductivity of composites.

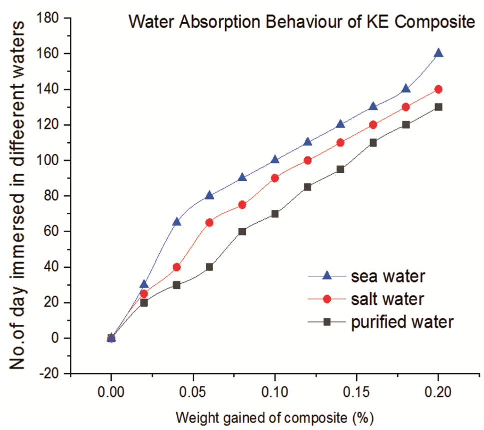

Fig. 8 — Water Absorption Properties of KE composite.

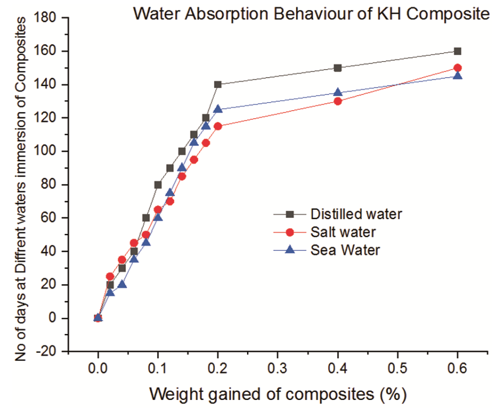

Fig. 9 — Water Absorption behavior KH composite.

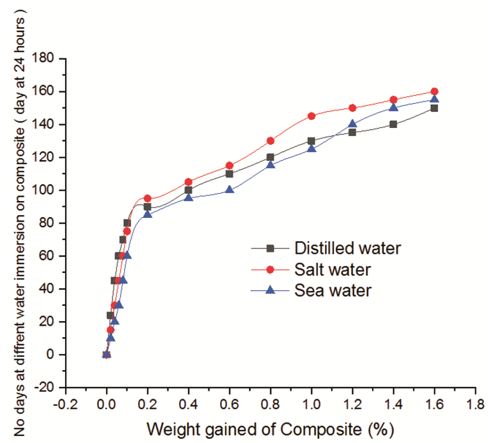

Fig. 10 — Water absorption behavior of KB composite.

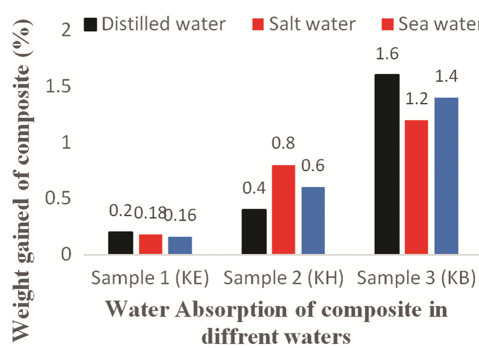

Fig. 11 — Comparative water absorption study of composites.

the water absorption properties of KE Composite.The samples were placed in sunlight for 3 hours at atmospheric temperature to remove moisture and dried out samples. All the samples were immersed in different waters, and the weight of the samples was measured regularly. Fig. 9 shows the water immersion behavior of KE composite linearly, increasing the water absorption percentage of the composite. Seawater immersed sample had higher water-resistant and lower water absorption of current composite. Fig. 10 shows the water absorption behavior of KB Composite. Eggshell filler volume percentage influenced water absorption behavior due to microvoids that damaged polymer chain structure and increased water absorption properties[38]. Fig. 11 shows the water absorption behavior of KH and KB Composites samples at different waters immersions over 160 days.Hairfiber and epoxy resin matrix bonding resisted water absorption due to fine microstructure to prevent the micro-cracks in the KH Composites. Banana bract having a dried surface and poor interlamination of composites created small voids, hollow structures, and micro cracks, which influenced the damage of the mechanical properties. The KB composite has higher water absorption properties than others, and seawater immersed samples have less water absorption than the others. Finally, it is concluded that the KH composite has better water-resistant properties.KE composite also had higher waterproofing materials, but properties depended on filler volume of percentage[39-40].

3.7 Microstructural analysis

The fracture surface SEM micrograph of currently developed composites is shown in Fig. 12. It shows the fine microstructure and developed fiber-matrix bonding of KE composite, which enhanced the mechanical properties. It shows the KE composite layer by layer formation and eggshell filler and broken eggshell particles with epoxy matrix, well-developed interfacial adhesion, and inert locked polymer chain. It shows dispersed pattern fiber after tensile fracture, and there is no evidence of micro-crack of hallow structure in the samples. It proved the

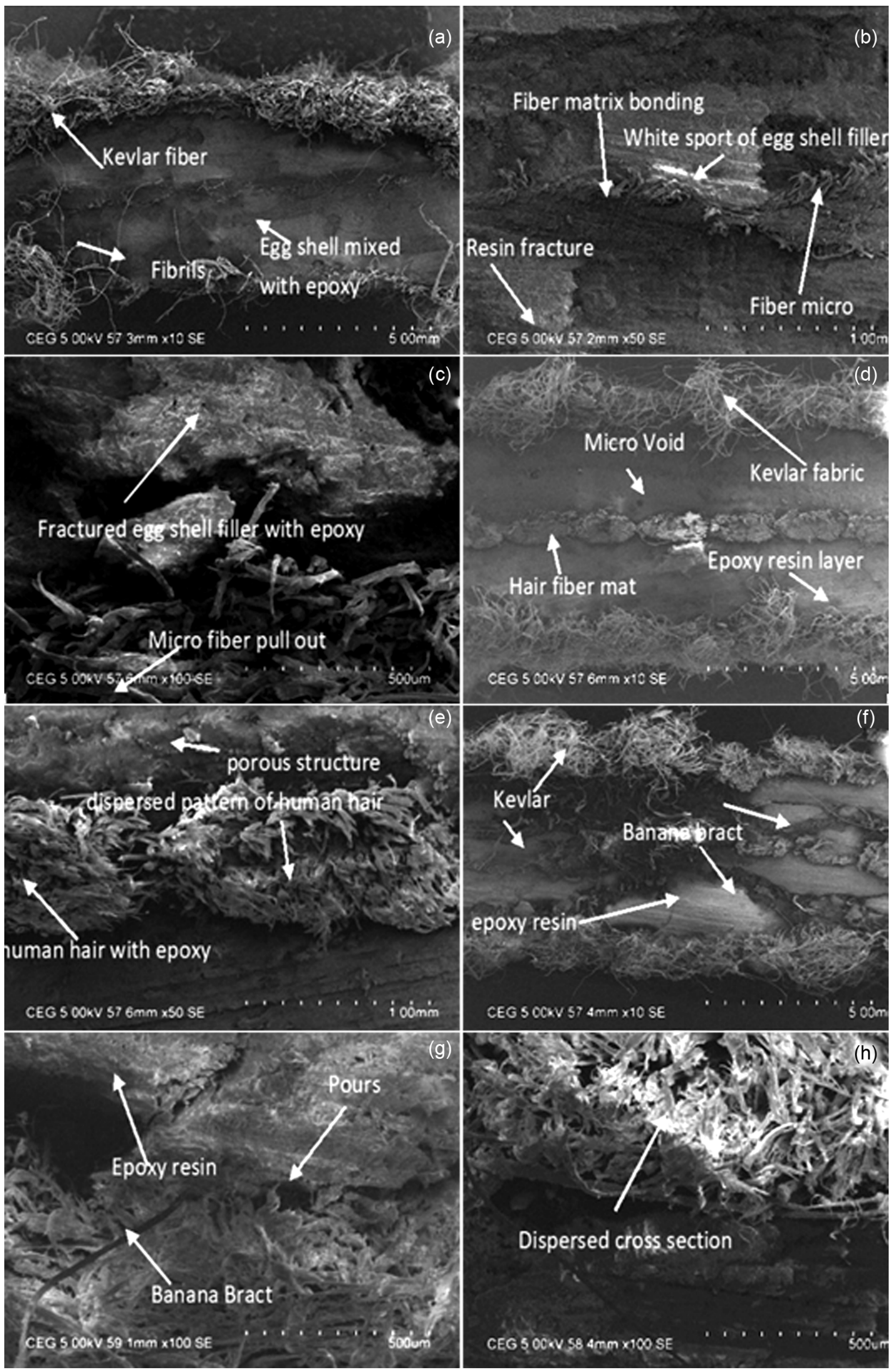

Fig. 12 — Micro structural analysis of Kevlar epoxy hybrid composites.

fiber presence having pores structure, microvoids, dispersed cross-section, fiber pull out, and fiber tear, which finally damaged the mechanical strength[20,41,42].

4 Conclusion

Kevlar- epoxy composites were developed with different kinds of the composition of eggshell filler, human hair fiber, and Banana bract fiber as per the hand layup technique. Tensile, flexural, impact, heat deflection, thermal conductivity, absorption properties, and morphological structure were evaluated for composite development. The KE composite has higher mechanical strength, low thermal conductivity, higher water resistance, and heat deflection, which withstands 75.5℃. Microstructure states fine fiber-matrix bonding and good adhesion between Kevlar epoxy resin. The volume of eggshell filler dominates the mechanical properties of KE composite and is used for structural and non-structural applications. The KH composite enhanced better properties than the KB composite, and heat deflection temperature was higher than the KE composite. Human hair fiber hasa more keratin structure which developed elasticity and flexural properties. The SEM images show interlocked polymer chain of Kevlar and human hair epoxy matrix.KE composite is used for thermoplastic and insulation materials applications. KB composite has fewer mechanical properties than the other fiber. Microstructure proved that inferior adhesion and microvoids damage the structural and mechanical properties. The future scope of the research needs to analyze fatigue behaviors and electromagnetic fields, sensor product-making applications. Finally, it is concluded that KE and KH have higher mechanical, thermal, and absorption properties than jute-epoxy and flax-epoxy composites. These composites can be used for shipbuilding applications for water flow passage, valves and engine covers, lining materials, and deck constructions due to higher mechanical properties, higher water resistance in seawater, low thermal conductivity, and high heat deflections.

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