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Characterization of natural – Synthetic fiber reinforced epoxy based composite – Hybridization of kenaf fiber and kevlar fiber

Muthukumaran Ramasamy [a], Ajith Arul Daniel [b], M. Nithya [c], S. Sathees Kumar [a], R. Pugazhenthi [b,*]

[a] Department of Mechanical Engineering, CMR Institute of Technology, Hyderabad 50140, Telangana, India
[b] Department of Mechanical Engineering, Vels Institute of Science, Technology & Advanced Studies, Chennai 600117, Tamil Nadu, India
[c] Department of Civil Engineering, CMR Institute of Technology, Hyderabad 50140, Telangana, India

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ABSTRACT

The work deals with the mechanical characterization of Kenaf and Kevlar fiber reinforced epoxy-based composites. The tensile, flexural, double shear, impact, hardness and de-lamination tests were conducted on composite laminates developed through hand lay-up process. Morphological analysis was conducted to examine the split surface of the tested specimen. The experimental investigation reveals that the mechanical properties of epoxy composites were enhanced by the hybridization of Kenaf and Kevlar fiber.

1. Introduction

Composite materials are one of the emerging materials over the past few decades. The application of composite material has grown steadily conquering the new markets and replacing conventional metal alloys. Composite materials are broadly used in automobile, aerospace, and construction industries for its light in weight, versatile in making different shapes without any compromise in structural and strength aspect. The most common form of composite materials is metal composites, ceramic composites, polymer composites and composite building materials. Generally, composites comprising of the matrix are being added with reinforcement in the form of fibers to improve their overall mechanical properties of the matrix. The performance of the newly designed composite depends on the choice and properties of the matrix and fibers. The property of a good matrix is that it must be able to deform easily and transfer the load evenly to the fibers. Synthetic fibers are being traditionally used in composite manufacturing. With the emergence of environmental awareness towards sustainability, there is a shift from the use of polymer fibers to plant fibers. The engineering research towards new polymer science for sustainable material emerged due to the worldwide availability of natural fibers from agro-waste. Natural fibers are abundant in quantity and exhibit remarkable characteristics viz., low density, low cost, a high degree of flexibility, less abrasive specific strength and modulus [1–3]. Besides, natural fibers possess some limitations such as high moisture absorption due to repelling nature, poor wettability, low thermal steadiness and variation in quality. Earlier studies have cleared the main factor that restricts the mechanical properties of natural fiber reinforced epoxy composites is the chemical incompatibility between plant fiber molecules and thermoplastic molecules [4].

In the recent past, most of the researchers have suggested hybridization, as a solution for the limitations of natural fiber as well as to decrease the use of synthetic fibers which are not environment friendly. Hybridisation is the process of using two fibers in a composite either natural fiber, artificial fiber or a combination of both natural or artificial fiber. Synthetic–nature fibre hybrid composites are contemporary materials used in a wide range of applications [15]. The availability of natural fibres is plenty in nature such as Kenaf, Bamboo. The incorporation of a suitable type of reinforcement for specific engineering applications needs to be studied. Literature have shown that natural fibres have excellent possibility to act as reinforcement in epoxy-based composites and few of the reviews are stated below.

Petrucci R et al. [5] assessed the properties of hybrid composite based on basalt fibers along with other fibres like hemp and glass.

* Corresponding author.
E-mail address: pugal4@gmail.com (R. Pugazhenthi).

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Laminates were prepared using epoxy with 21% to 23% fibre volume. The hybrid laminates have better mechanical performance than natural laminates and lesser than basalt composite. Therefore, incorporating hybrid fibers provides the best properties as compared to add single fibres in a composite. R. Yahaya et al. [6], formulated the intertwined Kenaf-Kevlar composites by changing the fibre content from 5.40 to 14.99 by volume fraction using two procedures. The composites were subjected to different impact loading and residual velocities using Ballistic measurements. The visual inspection of damaged samples reveals that hybrid woven (Kevlar-14 layers and Kenaf – 2 layers) composites have superior performance in comparison with other types of composites. Vishnu Prasad et al. [7] carried out the investigation on natural composite with normal resin and cashew nut shell resin as matrix and jute as reinforcing material. The hand lay-up method was adopted for manufacturing the fiber composite. The experimental work and numerical analysis using ANSYS were carried out to ascertain the tensile strength of the fiber composite. Authors have concluded that hybrid composite shows improved mechanical properties which is in turn validated using ANSYS software and hence the hybrid resin composite can be a substitute for synthetic resin. A. Azmira et al. [8] examined the effect of abrasive water jet machining process on surface roughness and a taper ratio of glass/epoxy composite. The process parameters were analysed and optimized using Taguchi's method and analysis of variance (ANOVA). Hydraulic pressure and machining parameters were influencing factors for surface roughness and kerf taper ratio respectively. The study concluded that operating pressure and feed rate affect the kerf width and delamination does not occur for abrasive water jet machined surfaces. B.S. Yilbas et al. [9], investigated the cutting region of Kevlar laminates by cutting it through laser through finite element coding and thermal data is verified through experimental temperature predictions. von Mises stress values are found to be very high at the cutting edges and at mid thickness due to temperature compression. Z.N. Azwa et al. [10] studied the characteristics of kenaf fibre with epoxy composites using alkaline characteristics exposed to high temperatures. The results showed that adding kenaf fibres marginally improves the charring and thermal stability of the specimens. Weight loss of the composites is insignificant at an increased temperature above 150℃. It is believed that all this work shows interest in composite using hybrid fibres with complementary properties. This current work is aimed to evaluate the mechanical properties and characterization of Kenaf and Kevlar fiber reinforced epoxy-based composite.

2. Materials

2.1. Kevlar

Kevlar is an aromatic polyamide fiber derived from benzene with extremely long molecular chains resulting in specific properties such as high toughness, the high degree of orientation, good resistance to abrasion, low density, high tensile strength, and high thermal chemical stability. Kevlar is being extensively used as a combustion protection material for aerospace applications and friction material in the automotive industry [11,14]. The Fig. 1 shows the photographic view of kevlar fiber.

2.2. Kenaf

With the recent interest towards the application of natural fibres in hybrid composite preparation, kenaf fibre is used in this study to achieve specific strength and elastic modulus at a lower cost. Kenaf is one of the natural fibers derived from the Kenaf-Hibiscus cannabinus, in the family of Malvacea. Kenaf bast fiber has the property of absorbing oil, high toughness, high aspect ratio and less in weight. Kenaf finds its wide application as oil absorbent, reinforcing fiber in thermoplastic composites, paper production on a limited basis, insulation and packing material [12]. The Fig. 2 shows the photographic view of kenaf fiber.

2.3. Epoxy resin

Composite specimens were prepared using easily available epoxy resin LY 556 to form the matrix and amine-based hardener HY 951 to induce adhesion and interfacial bond with the resin and fibers [16].

3. Fabrication process

The fibre reinforced hybrid composites were prepared using a hand lay-up technique as shown in Fig. 3. The mould was prepared using industrial rubber stripes, shaped according to the size of the specimen required. The fibres are dried for more than 2 days (24 h) under the hot sun, to remove the moisture. The fibres are then groomed and trimmed to the required length to fit the specimen mould. Epoxy resin was then mixed with a hardener in the ratio of 10: 1 to achieve the finest specimen composition. The entire specimen was prepared by stacking alternate layers of Kevlar (synthetic) fibre and Kenaf (natural) fibre with a coating of epoxy resin and hardener [17]. In total, five layers of fibres were stacked by laying woven mat of Kevlar fibre as the bottom layer and Kenaf fibre was laid second and fourth layer. After the application of resin, the roller is rolled over each layer to achieve better bonding between the fibre and resin. The roller used while the fabrication process also helps in removing the air pockets or bubbles formed to provide improved properties during the machining process. The composite was pressed at a temperature of 60 °C and a dead load was placed over it for a period of 8 h. The prepared composite sample of thickness 5 mm was removed from the mould to examine the mechanical properties like tensile strength, flexural strength,

Fig. 1. Kevlar fiber.

Fig. 2. Kenaf fiber.

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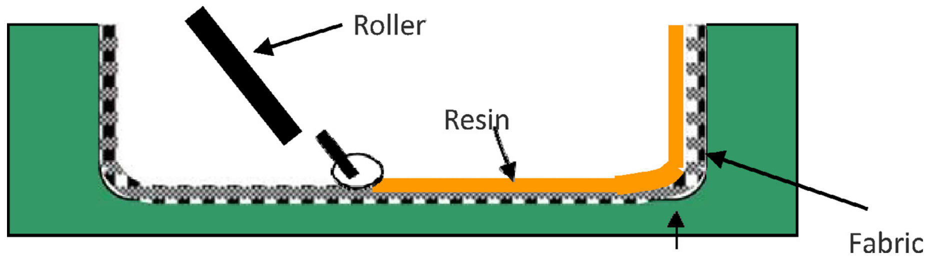


Fig. 3. Hand lay-up process.

Fig. 4. Fabricated specimen.

Fig. 5. Abrasive water jet machining AWJM setup.

impact strength, and also morphology analysis and machining of composite material.

The newly fabricated composite material as shown in Fig. 4 is cut into different standard specimen sizes and subjected to various testing processes as described in the subsequent section.

4. Machining of composite material

Abrasive water jet machining (AWJM) is an alternative to traditional machining techniques for material removal. In AWJM, removal of material occurs due to interface between a jet of water which is abrasive in nature and the sample specimen. In order to improve the efficiency of material removal rate, abrasive particles are mixed with a jet of water having high velocity. This mechanically advanced unconventional machining technology allows different materials such as metal, alloys, ceramics and composites to be machined effectively at the normal speed [13]. A typical AWJM equipment utilized in the current study is shown in Fig. 5.

The optimization of experimentation and process performance is carried out using the Taguchi method (TM) method of the orthogonal array. After the specimen preparation, the composite material is tested to determine its mechanical and morphological properties.

5. Taguchi analysis

The Taguchi method provides the best results to analyse and optimize the control factors on output performance. The Taguchi method contains the following steps:

- Selection of objective.
- Control factors and level selection.
- Orthogonal array construction.
- S/N ration determination.

The parameters mentioned in Table 1 are taken for the machining optimization process. In total, 9 combinations are been carried out to make the machining process in an effective manner. The Table 2 consists the experimental design values and the Table 3 consists the experimental results and corresponding S-N ratio.

Here MRR is carried out by using the formula

$$MRR = \frac{actual\ weight - final\ weight}{Time(\mathrm{min})}$$

The surface roughness is measured by using the surface pyrometer device. From this data the S/N ratio for MRR and surface roughness measured with the help of the Taguchi method. Fig. 6 Shows the S/N ratio graph for MRR and Fig. 7 Shows the S/N ratio graph for Ra.

6. Mechanical properties

6.1. Tensile strength

The tensile strength of hybrid composites determined is its ability to resist breaking under tensile stress. As per ASTM D638 standard specification, the specimen is cut in dog bone shape to carry out tensile tests using a universal tensile testing machine (UTM). The specimen is then loaded into tensile grips meant for the tensile tests in UTM. The extensometer is attached to the specimen before the commencement of the test. The tensile load is applied at the constant rate of speed and start separating the tensile grips. It takes nearly 30 s to 5 min for the specimen to break. Finally, the testing was ended and tensile strength was tabulated. Fig. 8 shows the composite specimen before and after the tensile test.

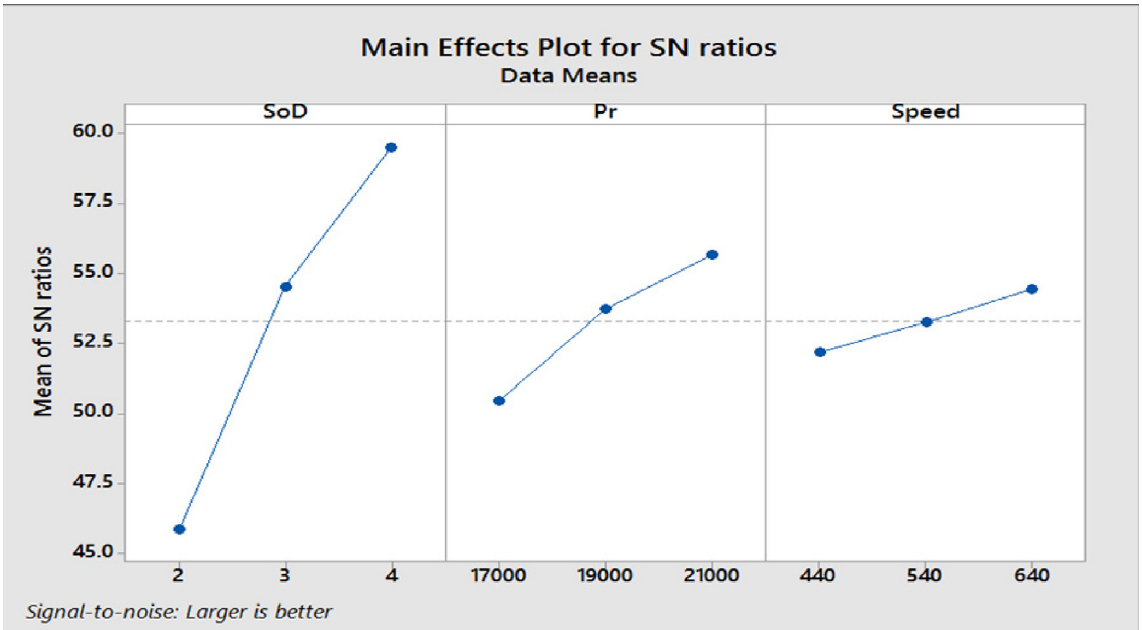


Fig. 6. S/N ratio graph for MRR.

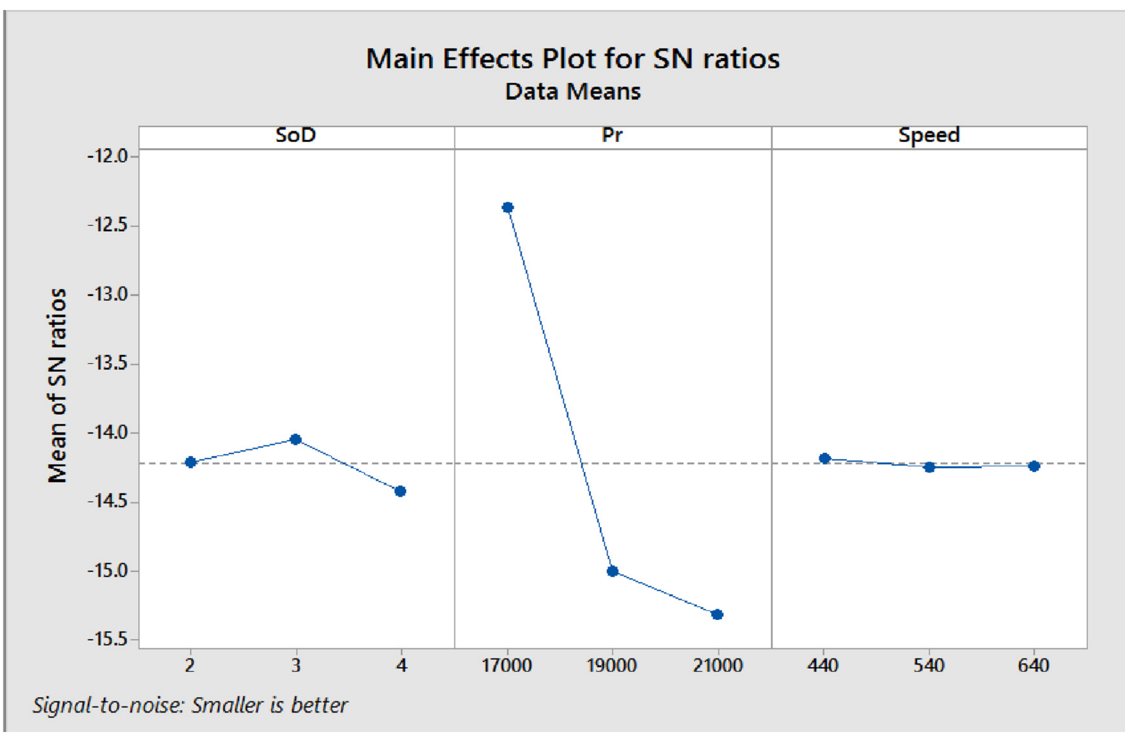


Fig. 7. S/N ratio graph for Ra.

Table 1
Levels of control factors adopted in the experiment.

Machining parameters /Input factors	Level 1	Level 2	Level 3
Standoff distance (mm)	2	3	4
Pressure (psa)	17,000	19,000	21,000
Traverse speed (m/s)	620	440	345

6.2. Flexural strength

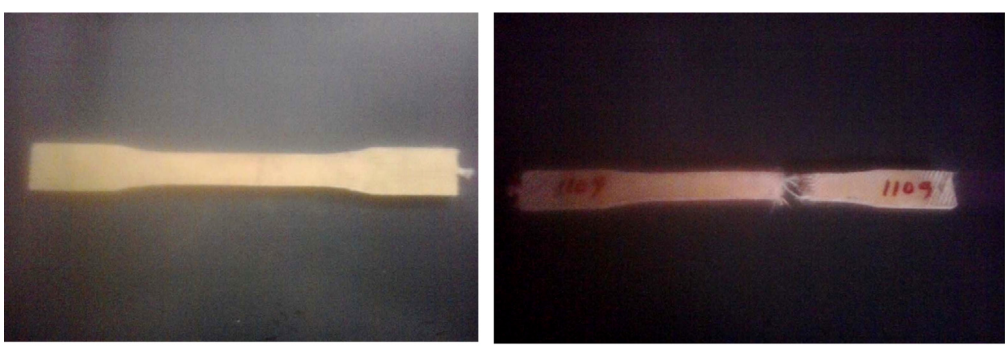
The flexural test is adopted to measure the flexural strength and modulus of composite used in structural applications. The failure mode of the hybrid fibre composite is found through the load extension curves obtained during the test. Testing was conducted in accordance with ASTM D 790–03 by applying 3-point loading

Table 2
Experimental design.

Standoff distance (mm)	Pressure (psi)	Traverse speed (mm/s)	MRR (g/min)	Surface roughness (μm)
2	17,000	440	108.043	4.125
2	19,000	540	216.086	5.603
2	21,000	640	324.129	5.853
3	17,000	540	420.168	4.095
3	19,000	640	552.220	5.517
3	21,000	440	648.259	5.654
4	17,000	640	816.326	4.237
4	19,000	440	960.384	5.745
4	21,000	540	1068.427	5.977

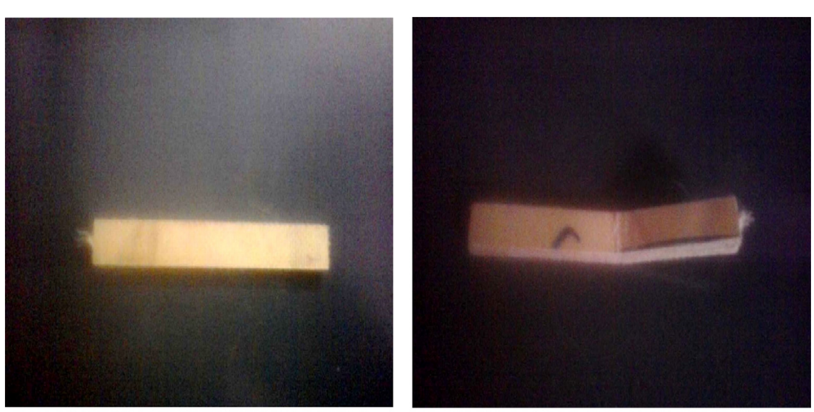
Table 3
Experimental results and corresponding S-N ratio.

Standoff distance (mm)	Pressure (psi)	Traverse speed (mm/s)	MRR (g/min)	Surface roughness (μm)	S/N ratio for MRR	S/N ratio for ra
2	17,000	440	108.043	4.125	40.6719	−12.3085
2	19,000	540	216.086	5.603	46.6925	−14.9684
2	21,000	640	324.129	5.853	50.2144	−15.3476
3	17,000	540	420.168	4.095	52.4685	−12.2451
3	19,000	640	552.220	5.517	54.8422	−14.8341
3	21,000	440	648.259	5.654	56.2350	−15.0471
4	17,000	640	816.326	4.237	58.2373	−12.5412
4	19,000	440	960.384	5.745	59.6489	−15.1858
4	21,000	540	1068.427	5.977	60.5749	−15.5297



(a) Specimen before tensile test (b)Specimen after tensile test

Fig. 8. Tensile test.



(a)Specimen before flexure test (b)Specimen after flexure test

Fig. 9. Flexural test specimen.

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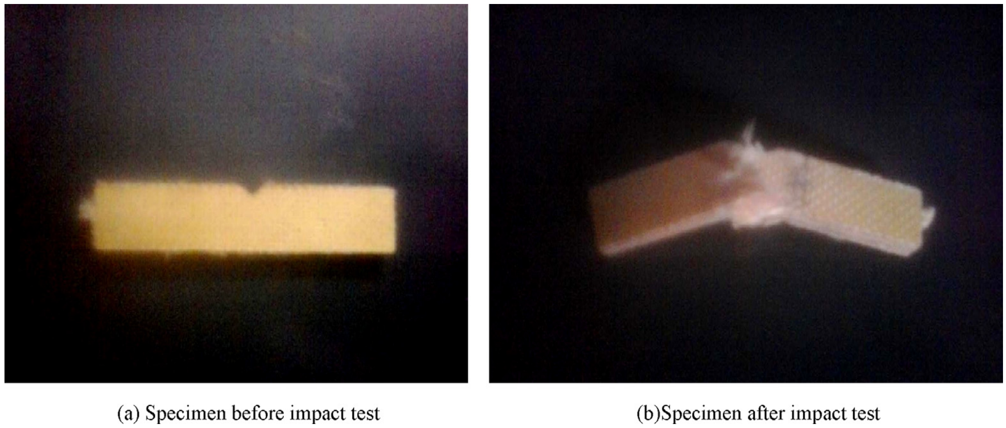

Fig. 10. Impact test specimen.

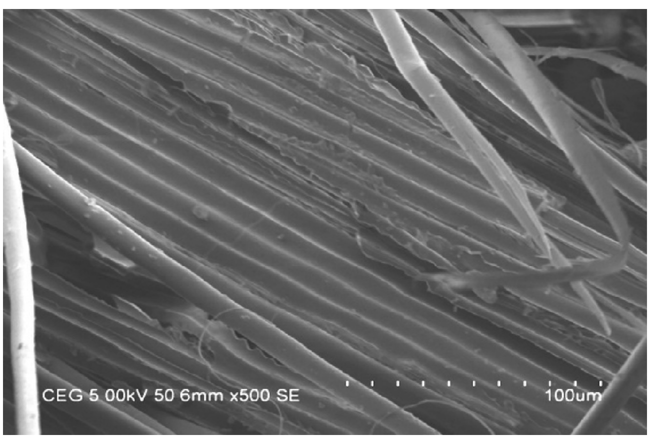

Fig. 11. SEM image of tensile test (100 μm).

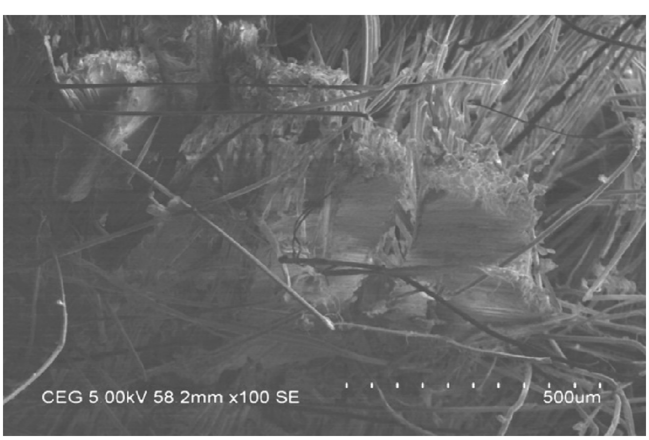

Fig. 12. SEM image of impact test (100 μm).

on the specimen. The rectangular specimens of size 100 mm × 20 mm were cut using a circular saw. The load was applied at a crosshead displacement rate of 5 mm/minute. The composite specimens were tested at room temperature by taking three samples for each test and average data were taken as a final result. Fig. 9 shows the composite specimen before and after the flexural test.

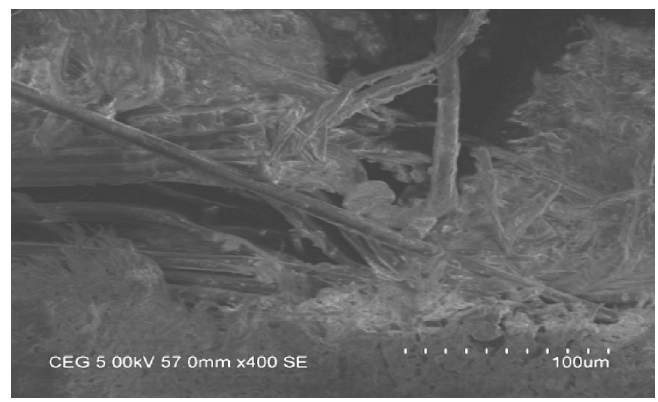

Fig. 13. SEM image of flexural test (100 μm).

6.3. Impact strength

Fiber-reinforced composite materials do not endure plastic deformation under impact loading. So, the impact test will result in elastic deformation or damage due to debonding or fibre failure. As per the ASTM D 256 standard testing procedure, the test arrangement was holding the specimen such that the notched side was facing the pendulum striking edge. The pendulum was released and allowed to strike through the hybrid composite specimen. The needle records the total energy stored by the composite specimen during failure. The impact energy absorbed by the specimen depends on the fibre – matrix bond. Fig. 10 shows the composite specimen before and after the impact test.

7. Morphological analysis

The Scanning Electron Microscope (SEM) technique was carried out to investigate the fracture surface of kenaf–Kevlar composite specimens to analyse the fracture behaviour and adhesion of fibre layers and the matrix of the hybrid composites. SEM surface morphology of kenaf– Kevlar composite is shown in Figs. 11–13. The figure clearly predicts that there is a failure in fibre matrix adhesion which resulted in the breaking of fibres at the point of loading in the flexural test.

8. Conclusion

The present work focused on the effect of kevlar - kenaf fibre loading on the mechanical characteristics of hybrid composites.

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The evaluation of tensile, flexural, and impact performance of hybrid composites clearly shows that properties are largely affected due to the presence of kevlar - kenaf fibre. Based on the experimental study on Hybrid fibre reinforced composite, the following conclusions were drawn:

- The ultimate strength of Kevlar- Kenaf composite is 110.36 N/mm2 which is suitable for automotive parts replacements.
- This fabricated Kevlar composite has a maximum break load of 6.60 kN thus withstanding more load before breaking also it has excellent wear properties which make them suitable for the effective replacement of piles in tyres.
- The experimental results analysis is carried out using Taguchi's analysis. The level of the best process parameters is determined by using ANOVA.
- From the SEM images, we can clearly see the cutting edges of the fibers, fiber pullout due to the testing process-induced damaged area.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Further Reading

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