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Mechanical Properties of Epoxy-Based Composite Reinforced with Kenaf, Grewia Serrulatta, Human Hair Fibers

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Abstract

Composite products (polymer based) finds application in industries such as automobiles, space, home appliances, the navy, and defense. This paper focused on preparing a composite specimen with natural fibers such as kenaf, grewiaserrulatta (grewia), and human hair to replace synthetic fiber. Epoxy resin BA LY 556 (Bisphenol-A) is considered a matrix material. Four specimens are prepared with 195 g of matrix and 105 g of fibers in the weight fraction method. Among 105 g fibers, the grewia fiber of 15 g is fixed constant, and the remaining 90 g of fibers, namely kenaf and human hair, are distributed as 0 g, 22.5 g, 67.5 g, and 90 g, respectively. As per ASTM standards, the mechanical property investigation was conducted, namely tensile, flexural, and impact tests. The result shows that the highest mechanical strength, i.e., tensile, flexural, and impact, are obtained in specimen A which is composed of 195 g matrix, 90 g kenaf, and 15 g grewia. Also, specimen B shows the highest strength in flexural properties, composed of 195 g matrix, 15 g human hair, and 90 g grewia. Additionally, microscopic analyses are conducted to verify the orientation and substrate bonding of fibers in the composites.

Keywords: Natural fiber; Flexural; Tensile; Impact; Strength.

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1. Introduction

Presently the requirement of low weight and high-strength material is increasing day by day. The use of fiber-reinforced polymer composites finds application in various industries such as automobile, space, navy, acoustic, etc. Moreover, the stringent traffic rules and regulations impose the use of helmets and other protective accessories, which require low weight, bio-compatible/ degradable, and eco-friendly characteristics. Research using natural fibers as reinforcement is sparse in which luffa, bamboo, jute, coir, and hemp fibers have been considered natural for the last decade. Babu *et al.* [1] have studied the mechanical properties of composite reinforced with alkali-treated and non-treated

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Esculentus Cyperus (EC) fibers. They have noted a significant improvement in the mechanical properties of alkali-treated EC fiber-reinforced composite. Artur *et al.* [2] made an attempt to use fiber on polyester composite for ballistic strength. The results were compared with the arrangements of fibers, such as fabric-type layers and aligned fibers, for the various volume ratios. They found that both types of fibers produce the same Ballistic impact on the composite. Ridzuan [3] prepared various natural fibers such as Napier, hemp, and pineapple fiber as filler material on epoxy composites by 5 to 10 % weight ratios. The use of natural fibers improved the mechanical property of the composites. Aofei *et al*. [4] studied the effect of chemically treated natural fibers such as kenaf using organic solutions such as NaOH, $NaClO_2$, $K_2Cr_2O_7$, H_2O_2, and $KMnO_4$. The H_2O_2-treated fiber shows 40 % of cellulose content, 26.8 % of crystallinity, and 18.9 % tensile strength compared to other treatments of fibers. Selvakumar and Omkumar [5] have used jute and human hair as fiber in commercial products such as door frames, biogas cylinders, railway coach interiors, etc. They checked the mechanical and thermal properties of the composite. 25 % of human hair composite provides higher tensile strength and flexural and double shear properties. Also, the increase in the % of human hair decreases the low moister absorptivity, and thereby increasing the % of jute causes the high thermal stability in the composite. Wajid *et al.* [6] investigated the composite's soil mechanical properties by adding human hair as reinforcement. They have obtained almost no cracks in this composite and significant improvement in mechanical properties. Some of the researchers are taken the initiative with animal hair also as a fiber in the composite. Isiaka *et al*. [7] tried animal hair, such as chicken feathers and cow hair, as reinforcement in the composite. They have compared the results of composites by flexural and tensile strength. The treated chicken feather and cow hair play a significant role in increasing mechanical properties. Alavudeen *et al*. [8] used the banana and kenaf fiber in the composite with two different weaving patterns: twill and plain. The results show that the plain-type composite provides more mechanical strength than the twill-type pattern. Also, they have noted the significant strength improvement in fibers with alkali and sodium sulfate treatment. Karaduman *et al*. [9] tried the enzyme-treated jute fiber in polyester composites. They considered the enzymes like cellulose, xylanase enzyme, and pectinase for the treatment of fiber, and results were compared with NaOH solution-treated fiber. The enzyme-treated fibers show notable improvement compared to NaOH solution-treated fiber. Yousif *et al.* [10] investigated the effect of NaOH-treated kenaf fiber on the interfacial adhesion properties of the fiber. They noticed that the treated kenaf fiber mixed epoxy composite increased the Flexural strength from 20 % to 36 % when compared with untreated fibers mixed epoxy composite. Moreover, due to its low interfacial adhesion properties, the untreated fiber composite results in tearing, debonding, and pulling out. Mansour *et al*. [11] used fibers in polyester matrix composite and noticed that alkalization-treated fibers show better flexural properties on comparing with untreated fiber composites. Also, the flexural properties of fibers are decreased when increasing the timing of alkali treatment with NaOH. Harish *et al*. [12] studied the mechanical properties of coir and glass fiber in the epoxy-based composite. They have noticed that the tensile, flexural, and impact strength of the coir composite is higher than the glass fiber composite due to the high adhesive bonding of resin and fibers. Various attempts have been made by researchers worldwide for the last decade on synthetic and natural fibers. It is clear from the literature that the fabrication of composites in a combination of grewia, kenaf, and Human hair is sparse. Although some researchers use these fibers separately as a reinforcement in composites, no attempt has been made to combine these fibers since these fibers expose high efficacy towards mechanical, heat, and chemical resistance [12]. Hence in this study, Grewia serrulatta, kenaf, and human hair are combined together as fiber reinforcement in different volume fractions for the composite fabrication. Mechanical properties such as flexural, tensile, and impact strength are considered for the composite evaluation. The optical microscope images are used to determine the fiber adhesiveness of the specimen.

2. Experimental Method

2.1. *Materials*

The easy to handling, low viscosity, and transparent BA epoxy resin 556 (Bisphenol-A) is used as a matrix, and curing agent HY 951 is used as a hardener. The resin and hardener were mixed completely in the ratio of 10:1 by the weight fraction method, which is supplied by M/s. Hereinba enterprises, Chennai, India. The properties of epoxy and hardener composite were displayed in Tables 1and 2, respectively.

Table 1. Properties of epoxy.

Constituent of Resin	Viscosity (at RT)	Density (at RT)	Chemical composition	Visual type
Epoxy	10,000–12,000 MPa s	1.15–1.20 g cm^{-3}	Bisphenol-A Based	Transparent, pasty yellow liquid

Table 2. Properties of hardener.

Constituent of resin	Viscosity (at RT)	Density (at RT)
Hardener	10–20 MPa s	0.95–1.05 g cm^{-3}

The grewia fibers are found in the fully grown branches of the grawia serrlutta tree. The stems from the serrlutta tree branch were immersed in the water for four days and extracted the fibers manually without visible damage. By nature, this fiber contains cellulose, hemicelluloses, and lignin in the range of 60 %, 22.5 %, and 17.5 %, respectively. The grewia fibers are used by local people for making ropes, knots, bags, threads, baskets, etc. [13]. Kenaf is a natural fiber extracted from the hibiscus cannabis plant cultivated in tropical and subtropical regions. Kenaf fibers contain 40.8 % cellulose, 34.2 % hemicelluloses, 22 % lignin, 2.5 % pectin, and other composition. The average height of the fiber is 1 m to 1.5 m and 1.5 to 2 cm in diameter in India [14]. Human hair is purchased from a nearby location, and it is one of the non-decomposable wastes which possess high tensile strength and very less weight [15].

2.2. *Treatments of fibers*

The fibers of grewia serrulatta and kenaf were collected and immersed in water for four days. The fibers are soaked at room temperature after extracting from the stem by using a metal wire brush. The extracted fiber strands are split into single strands manually and made into single strands with a length of 300 mm. At room temperature, the sodium hydroxide (NaOH) solutions of 2 % were used for the alkaline treatment of fibers. The fibers are immersed into the solution, washed and dried in the sunlight for 2-4 days, and made into bundles [16]. In the case of human hair, it is a natural fiber formed of keratin that has physical properties such as elasticity, smoothness, and softness. The human hair fibers are gathered, treated with NaOH solution, and prepared for a length of 8-10 mm. In order to remove dirt and impurities in fibers, it is treated with NaOH. The hairs are rinsed in hot water and then dried at room temperature to improve the surface adhesive characteristics by removing artificial impurities.

2.3. *Processing of composites*

The mold is prepared for the dimensions of 300×300×30 mm^3 using a commercial stainless-steel plate. The mold was cleaned with a thinner solution, and wax was applied to the mold surface after the curing process. The resin and hardener were stirred in a ratio of 10:1 and poured into the mold. The fibers are arranged in a unidirectional orientation over the resin, and this arrangement was repeated two times. Finally, the mold was fixed and covered in the compression molding machine using the metal plate. During this process, pressure and temperature are maintained between 1800-2000 psi (12-13.8 MPa) and 300 °F to 375 °F (149 °C to 191°C), respectively. Then the mold was allowed to cure for 30-45 min. In order to complete the curing process, specimens are post-cured in an oven at 80 °C for two hours and cooled down to room temperature. These steps are followed for all specimens whose weight fractions are shown in Table 3.

Table 3. Percentage of weight fraction.

Specimen name	Epoxy (g)	Kenaf (g)	Grewia serrulatta (g)	Human hair (g)
A	195	90	15	0
B	195	0	15	90
C	195	22.5	15	67.5
D	195	67.5	15	22.5

2.4. *Characterization of composites for tensile strength*

The tensile testing was conducted according to ASTM standard D3039 designation, and the prepared Composite sheets were cut to the required dimension (120 × 25 × 4 mm). The Universal testing machine (UTM) KIS-2-1000 is used to test the tensile strength of the specimen, which has a capacity of 100KN supplied by M/s Kalpak instruments and controls, Pune, India. During the test, 2 mm/min cross-head speed rate is applied to the specimen. The applied specimen and testing machine are shown in Fig. 1. The results and the mean values obtained from experiments are displayed in Table 4.

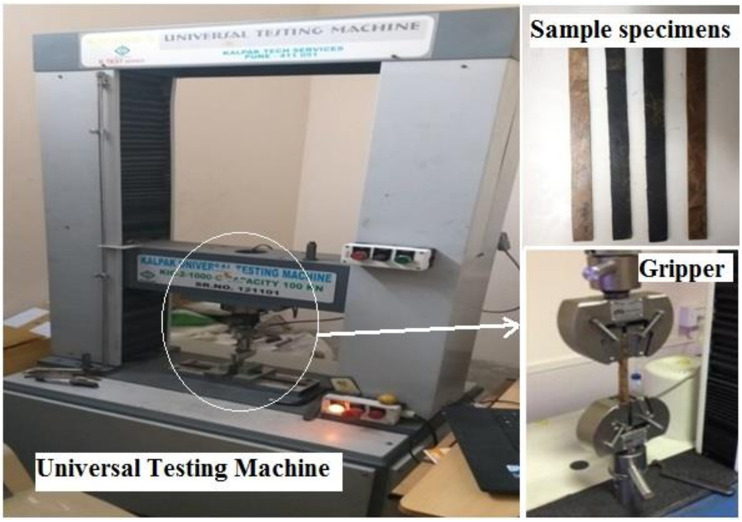

Fig. 1. UTM setup for tensile test.

Table 4. Results of tensile test.

Parameters	Specimen A			Specimen B			Specimen C			Specimen D		
	1A	2 A	Mean	1B	2 B	Mean	1C	2 C	Mean	1D	2 D	Mean
Cross Section Area(mm^2)	75	75	75	75	75	75	75	75	75	75	75	75
Peak load (N)	1955.62	1959.32	1957.62	548.85	549.18	549.05	977.7	976.6	976.6	1421.08	1423.04	1422.03
Deflection (%)	0.920	0.960	0.940	0.789	0.791	0.790	0.729	0.729	0.732	0.660	0.675	0.670
Tensile strength (MPa)	27.22	25.10	26.10	7.316	7.333	7.318	13.05	13.05	13.18	18.89	19.35	18.96

2.5. *Characterization of composites for flexural strength*

ASTM D 790: test method is followed to identify the flexural strength of the composite. The specimens are prepared as per the ASTM dimensions of 120 × 13 × 4 mm. The flexural test was conducted using a three-point bend setup in UTM. In order to avoid the misalignment, a 100 mm length has been maintained between the two supports, which is illustrated in Fig. 2. The ultimate load-carrying capacity of the specimens is noted, and the results are listed in Table 5. The flexural strength, strain, and flexural modules of all specimens are determined using equations 1, 2 and 3, respectively. Where σ_F is flexural strength in MPa,ε_f is the strain, X is flexural modulus in GPa, L is span length, b is the width, and D is the deflection in mm.

$$\sigma_F = \frac{3PL}{2bt^2} \quad (1)$$

$$\varepsilon_f = 6Dt/L^2 \quad (2)$$

$$X = {}^{\sigma f}/_{\varepsilon f} \quad (3)$$

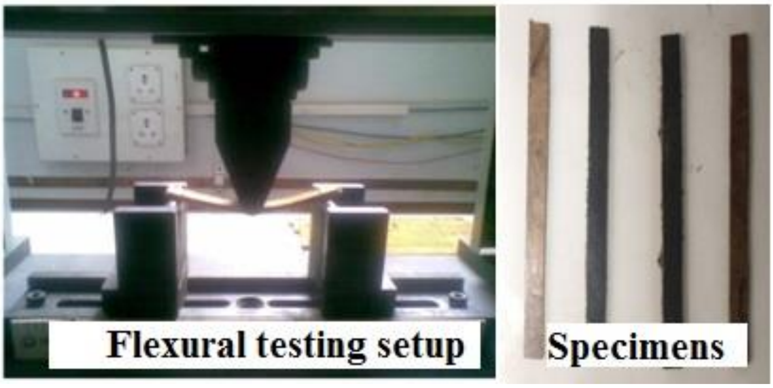

Fig. 2. Flexural testing setup.

2.6. *Characterization of composites forImpact strength*

The dimensions of 65 × 13.2 × 4 mm are followed in accordance with ASTM D 256 to find the impact strength. The test was conducted with an Izod impact testing machine, which is supplied by M/s International Equipments, Mumbai, India. The specimens were fractured and noted the energy while it was broken. The Impact strength is calculated using equation 4. The impact testing setup is displayed in Fig. 3, and the experiment results are shown in Table 6. Where I is the impact strength, K is the energy absorption by the material during fracture, and A is the cross-sectional area for the specimen in mm^2.

$$I = \frac{k}{A} \quad (4)$$

Table 5. Results of the flexural test.

Parameters	Specimen A			Specimen B			Specimen C			Specimen D		
	1A	2A	Mean	1B	2 B	Mean	1C	2 C	Mean	1D	2 D	Mean
Cross Section Area mm^2	39	39	39	39	39	39	39	39	39	39	39	39
Peak load [N]	181.5	181.9	181.6	185.8	185.0	185.8	98.97	100.8	100.2	164.4	165.0	164.8

Flexural Modulus (GPa)	55070.05	55085.88	55076.057	9194.81	9196.34	9195.817	49600.75	49615.62	49609.752	80163.13	80170.82	80167.134
Flexural strength (MPa)	147.4	145.4	146.7	148.6	152.	150.1	78.62	81.98	80.96	133.0	133.2	133.1

Fig. 3. Impact testing setup.

Table 6. Results of impact test.

Parameter	Specimen A			Specimen B			Specimen C			Specimen D		
	1A	2A	Mean	1B	2B	Mean	1C	2C	Mean	1D	2D	Mean
Impact strength kJ/mm^2	2.2	2.1	2.15	1.8	2.2	2	2	2.1	2.05	2.3	2.1	2.2

3. Results and Discussion

3.1. *Effect of fibers on tensile strength*

Fig. 4 (a) shows the influence of fibers on the tensile strength of four different specimens. Based on the graph, specimen a produces a higher tensile strength of 26.04 MPa, which is the highest value when compared to the other specimens. Specimen A contains 90g kenaf and 15 g grewia fiber along with the matrix; the bar graph shows that the higher % of kenaf fiber volume increases the tensile strength in the composite. Generally, kenaf fibers are highly composed of hemicelluloses and lignin content which act as a bonding agent between fibers and matrix [17]. Therefore, specimen A provides 3.56 times higher tensile strength than specimen B. Also, 15 g of grewia fiber plays a major role in the composite. The use of 15 g of grewia fibers in specimen D, along with 67.5 g % kenaf and 22.5 g of human hair, produces 2.53 times lower tensile strength than specimen A. The presence of unidirectional orientation of fiber in composite causes the higher tensile strength in the specimen [18]. Specimen C produces the 13.037 MPa tensile strength, which is 0.78 times higher than specimen B. It's due to the fact that the presence of human hair in composite contributes to lesser tensile strength. The addition of human hair reduces the bonding effect due to the presence of keratin in cellulose and polished surfaces. However, in natural cellulose, the presence of fiber increases the bonding strength of the composite, which leads to higher tensile strength in specimens A, D, and C, respectively [19].

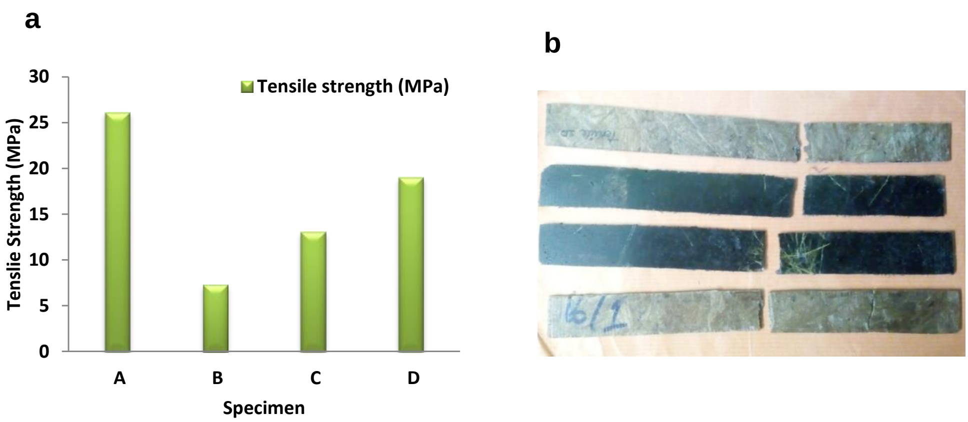

Fig. 4. (a) Influence of fibers on tensile strength and (b) tensile testing specimens.

3.2. *Effect of fibers on flexural strength*

Fig. 5 shows the influence of fibers on the flexural strength of four different specimens. According to the graph, specimen B produces 150 Mpa flexural strength, which is 0.85 times higher value than specimen C. The use of human hair and kenaf fibers in composite plays a major role in flexural strength. Specimen B and A are composed of 90 g human hair, 15 g grewia, and 90 g kenaf, 15 g grewia, respectively. Human hair is a tough fiber and highly strong, also elastic in nature. The property of human hair increases its regaining ability which causes the higher flexural strength in specimen B. Specimen A produces 146.7 MPa flexural strength, which is 0.81 times higher than specimen C. The presences of kenaf fibers improve the molecular strength of fiber and resin. This phenomenon improves the flexural strength of the composite against the deformation load. The application of human hair shows a reasonable impact on the composites. The specimen D and C produces 133.2 MPa and 81 MPa, respectively, for flexural strength. In these specimens, 67.5 g of human hair and kenaf fibers are used for specimens D and C, respectively. Specimen D shows a higher flexural strength than that specimen C. In general, 65 to 95 % of human hair is composed of protein and water molecules which help the composite withstand high loads.

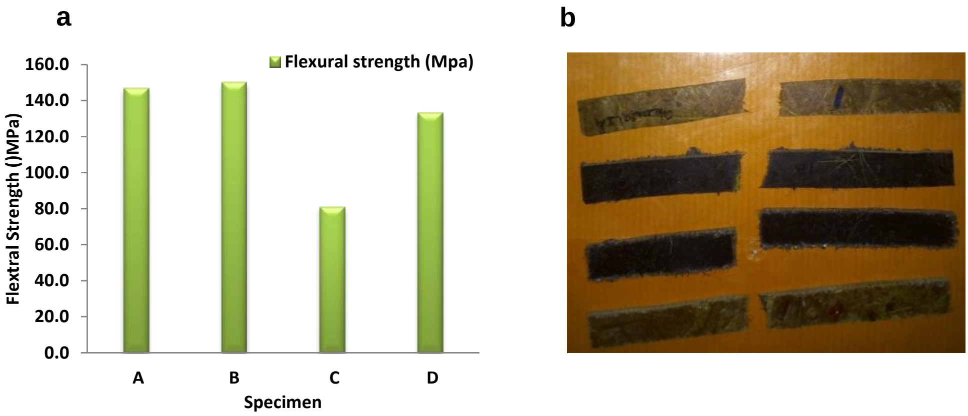

Fig. 5. (a) Influence of fibers on flexural strength and (b) flexural testing specimens.

3.3. *Effect of fibers on impact strength*

Fig. 6 shows the influence of fibers on the Impact strength for different specimens. The graph inferred that specimen A produced 2.15 KJ/mm^2 impact strength, which is 7.5 % higher than specimen B. The kenaf fiber shows a significant role in impact strength. Specimen A and B are composed of 90 g kenaf, 15 g grewia, and 90 g human hair, 15 g grewia, respectively. Generally, the kenaf fibers molecules show tight connectivity within themselves. This characteristic increases the high load-carrying capacity of specimen A. In the case of specimen B, the high elasticity of human hair results in low impact strength. Specimens D and C show 2.1 KJ/mm^2 and 2.05 KJ/mm^{2,} respectively, for impact strength. Therefore, specimen D and C shows 5 % and 2.5 % improved impact strength when compared to specimen B, respectively. The high interfacial bonding between fiber and polymer leads to the higher impact strength in specimens D and C.

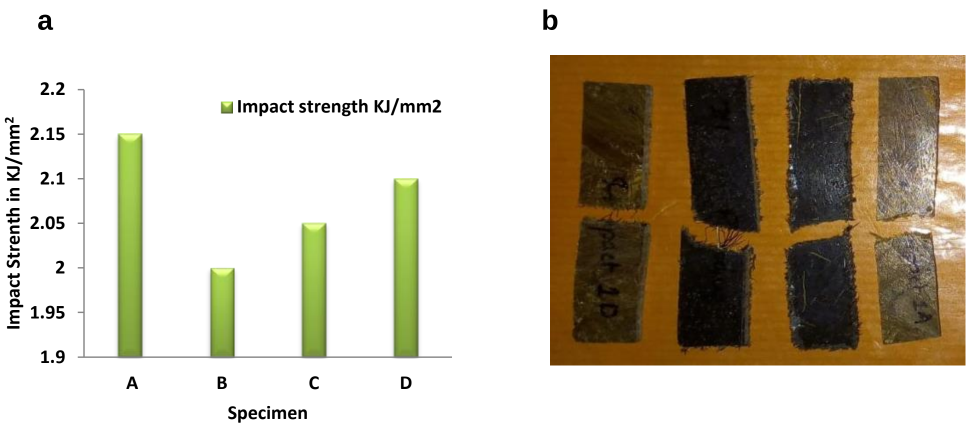

Fig. 6. (a) Influence of fibers on impact strength and (b) impact testing specimens.

3.4. *Morphological analysis*

The microscopic image analyses are conducted to understand the effect of fiber orientation on the tensile test. The experimental result shows that the specimen shows good mechanical characteristics compared to other specimens [20]. Therefore, specimen A is considered in microscopic image analyses, which consists of 30 % kenaf and 5 % grewia fiber and the remaining matrix. Fig. 7 (a) shows the microscopic image of the specimen before the tensile test. The figure shows the unidirectional fiber orientation on the specimen. Also, in some of the places, the presence of voids is noticed, which is due to laying inaccuracy. Fig. 7 (b) depicts the microscopic image of the specimen after the tensile test. The presence of fibers was noticed on the broken edges and delaminated zone.

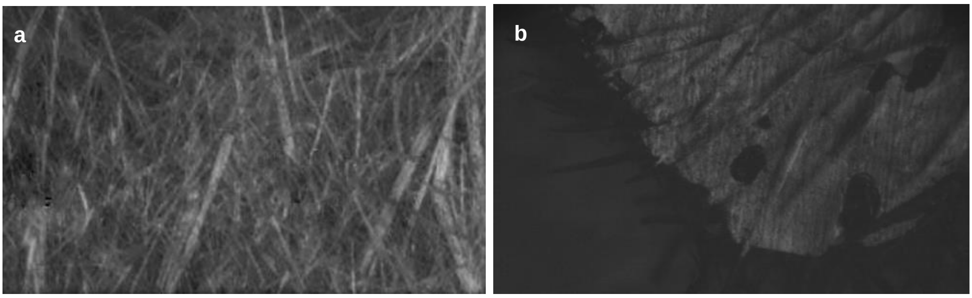

Fig. 7. Tensile tested image (a) before and (b) after.

4. Conclusion

In this paper, natural composite material is developed with natural fibers such as grewia, kenaf, and human hair on the epoxy and studied the mechanical properties. Based on the evaluation, specimen A, with the composition of 195 g matrix, 90 g kenaf, and 15 g grewia, produces 3.56 times higher tensile strength than specimen B. The highest flexural strength is obtained on specimen A with the composition of 195 g matrix, 90 g human hair, and 15 g grewia. The graph inferred that specimen A produces 2.15 KJ/mm^2 impact strength, which is 7.5 % higher than specimen B. The microscopic analysis results confirm the unidirectional orientation of fibers in composites. Hence, human hair can be applied for the fabrication of composites wherever the flexural property is desirable. The research can be further extended to machinability studies of natural composites. Moreover, other properties such as hardness, and thermal and tribological properties can be studied.

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