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Impact of Water Absorption on Tensile Strength: A Comparative Study of Jute Fiber Composites with Various Fiber Content

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Mohammad Salman Haque[1,2*], Istiak Ahmed Ovi[1], Farah Samsi Prome[1], Anika Hossain[1]

[1] Materials Science and Engineering Department, Khulna University of Engineering and Technology, Khulna-9203, Bangladesh
[2] Materials and Metallurgical Engineering Department, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

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ABSTRACT

The study focuses on replacing environmentally harmful synthetic materials with natural, renewable, and biodegradable jute fibers in Bangladesh. The hand-layup method incorporates Long jute fibres unidirectionally in an epoxy resin matrix. The primary goal of this research is to examine the effects of different fiber volume fractions on the tensile strength of the composite and how that strength is affected by the composite's water absorption behavior following two months of weathering in water. The reduction in the tensile strength of weathered samples is attributed to the loss of fibres' structural integrity upon water absorption compared to raw samples. After being exposed to the water, the tensile strength of a 5% fiber composite sample drops by around 16.43%, whereas an epoxy sample with 15% fiber reinforcement drops by about 28.93%. The interactions between the fibers and the epoxy matrix, as well as the morphology of the fibers following fracture, were analyzed by SEM for both raw and weathered samples. Fiber-matrix debonding and fiber swelling due to water absorption and voids are observed in weathered specimens, whereas perfect fiber-matrix bonding is evident in raw composites.

Keywords:
Composites, Jute fiber, Polymer, Water absorption, Fracture surface

1. Introduction

The use of polymer composites has increased significantly in recent years due to their superior properties and versatility. Two or more distinct materials are combined to form polymer composites, which can be combined to achieve specific properties that are not possible with a single material. For example, a polymer composite can be made to be strong, lightweight, and corrosion-resistant. Composite materials are significantly stronger than their counterparts due to their high strength-to-

* *Corresponding author.*
E-mail address: *salmanhaque@mse.kuet.ac.bd* (Mohammad Salman Haque)
E-mail address of co-authors: *ovi1827035@stud.kuet.ac.bd, prome1827034@stud.kuet.ac.bd, hossain1827036@stud.kuet.ac.bd*

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weight ratio [1-3]. Due to their minimal maintenance requirements, these composite materials are more durable than traditional materials. Additionally, they can maintain their shape in many environments due to their greater dimensional stability and lower fracture toughness than most metals and alloys. They are less corrosion-resistant in severe environments. The escalating apprehensions regarding the ecological consequences of traditional materials have led to a swift surge in the requirement for sustainable substitutes [4-7].

The growing demand for biodegradable products has significantly reduced the use of artificial materials, mainly in the packaging, structural engineering, and automotive industries. The utilization of natural fiber composites has emerged as a compelling substitute due to their extensive accessibility, uncomplicated processing techniques, versatility in design, and capacity to be shaped into intricate configurations [8-10]. Jute fiber is of great value due to its exceptional mechanical characteristics, such as its high tensile strength, remarkable stiffness, and thermal stability. The integration of jute fibers enhances the composite materials' comprehensive functionality, leading to elevated levels of tensile strength, torsional rigidity, and impact resistance. Jute fiber composites exhibit exceptional tensile strength, rendering them appropriate for employment in structural contexts [11-12]. The qualities of natural fiber composites can be improved by chemical treatments. The chemical treatment of the fiber by NaOH removes the oil, wax, and hemicellulose content from the fiber. These modifications may result in an enhanced interface between the fibers and the polymer matrix, which may enhance the composite's mechanical properties [13-15].

Natural fibers, however, provide several benefits over synthetic fibers, such as lower costs, lower densities, and higher specific strengths. Nevertheless, there are several drawbacks to using natural fibers, including their hydrophilicity, which can lead to water absorption and a weak bond between the fiber and the polymer matrix [16-18]. Thus, the impact of the absorption of water on the strength of composites made of jute fiber was examined in this study. The findings demonstrated that the amount of jute fiber added increased the water absorption rate. This is due to jute fibers' hydrophilicity or their high affinity for water. The interactions between the fibers and the polymer matrix may weaken when the fibers swell after absorbing water [19-21]. The composite may become weaker after the water absorption. To further understand the impact of water absorption, the cracked surfaces of the composites were examined using scanning electron microscopy (SEM). SEM images demonstrated that the fibers swelled and delaminated from the polymer matrix because of water absorption. The load-bearing capability of the composite was reduced because of this delamination.

2. Methodology

2.1 Raw Materials

The present study employed jute (*Corchorus Capsularis*) fibers to be the reinforcing agent in the fabrication of composite specimens. Procuring epoxy resin, corresponding hardener, and jute fibers was carried out through a nearby vendor. The selection of unidirectional jute fibers for this research was based on their advantageous mechanical properties and sustainable attributes.

2.2 Composite Sample Preparation

The composite slabs are fabricated using the conventional hand lay-up technique, followed by the utilization of light compression molding. Three distinct fiber percentages, such as 5%, 10%, and 15%, were employed to generate three sets of composite samples, as shown in Table 1. They were treated with NaOH for better bonding with the matrix [22-23]. Then, they are heated to 60^{o}C for 2 hours to remove the moisture. Following the recommendation, the epoxy and hardener are blended at a weight ratio 10:1 [24]. The jute fiber was impregnated with the pre-existing matrix material. During the preparation process, vacuum degassing was done to avoid the formation of air bubbles in the epoxy matrix, and epoxy was cast into the mold. The mold was subjected to top-down pressure and allowed to cure for 48 hours at ambient temperature [25]. After 48 hours, the specimens were extracted from the mold and resized to the required dimensions (Figure 1).

Table 1
Distribution of fiber contents in the matrix

Sample	Fiber Percentage (%)	Matrix Percentage (%)
1	5	95
2	10	90
3	15	85

2.3 Tensile Strength Testing

The present study involved conducting tensile tests on specimens featuring linear edges (Figures 1c and 1d). The tensile properties of composites reinforced with fibers are commonly evaluated using the ASTM D3039-14 standard test [26-27]. The tensile tests were conducted utilizing an Instron 1195 universal testing machine with a 2 mm/min crosshead speed. The values obtained were utilized to determine the tensile strength of the composite samples. Three identical specimens were assessed for each composite type, and subsequently, the mean value was reported as the most indicative characteristic of that specific composite to ensure statistical validity.

2.4 Weathering and Water Absorption Test

Composite specimens were subjected to a two-month weathering exposure in water under controlled environmental conditions. Each specimen's weight and water absorption behavior were periodically measured during the weathering period. Following the weathering period, tensile strength testing was performed on the weathered composite specimens using the same methodology as tensile testing.

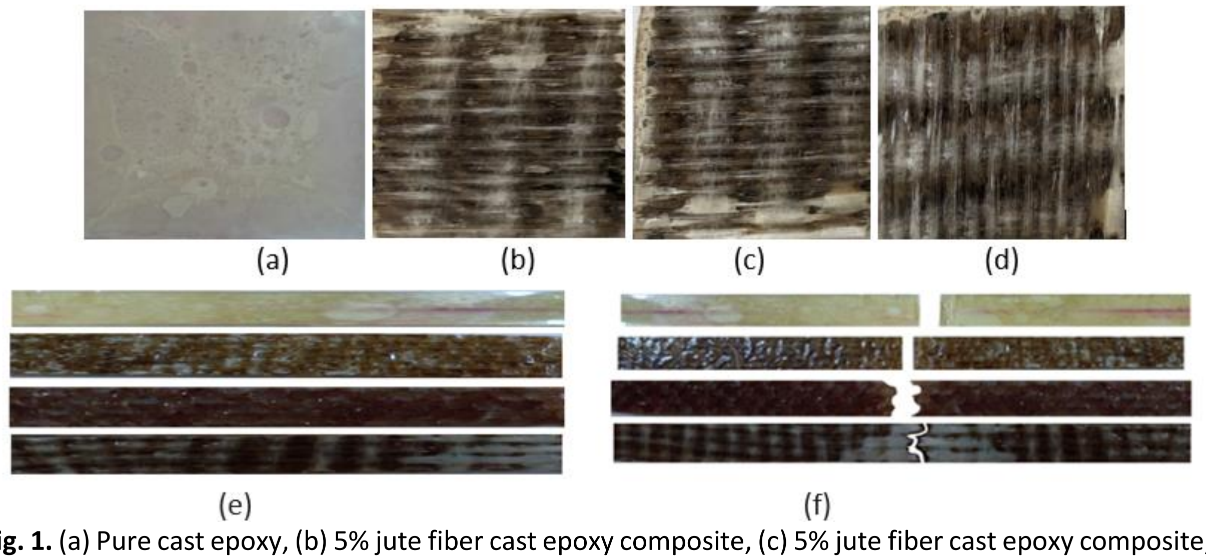


Fig. 1. (a) Pure cast epoxy, (b) 5% jute fiber cast epoxy composite, (c) 5% jute fiber cast epoxy composite, (d) 15% jute fiber cast epoxy composite, (e) Standard tensile samples, and (d) Fractured samples after the tensile test

3. Results

The observed enhancement in the tensile strength of epoxy composites upon incorporating varying proportions of jute fiber (5%, 10%, and 15%) can be attributed to the gradual reinforcement effect and the improved load transfer mechanism between the jute fibers and the epoxy matrix.

With pure epoxy, the average tensile strength was 30.53 MPa shown in Figure 2. However, it has been observed that the average tensile strength is 38.33 MPa when adding 5% jute fibers to the pure epoxy. Furthermore, compared to pure epoxy, a 25.55% increase in strength is noted. Using jute fibers increases the tensile strength over epoxy alone by distributing and transmitting the applied load more efficiently [28-29]. As fiber are stronger than matrix, it effectively increased the strength of the composites. Specifically, adding jute fibers at a concentration of 10% results in an increase in the strength of the composite, as more fiber contents helped carry out the load and improved the strength [30]. The composite material exhibited an increase in strength, measuring at 50.86 MPa, representing a nearly 66.6% improvement compared to pure epoxy strength.

Consequently, the load distribution throughout the composite material is enhanced, thereby reducing stress concentrations and augmenting its tensile strength. Incorporating 15% jute fiber results in a noteworthy enhancement of the tensile strength compared to the preceding instances. The mean tensile strength rose to 67.16 MPa, signifying a 120% increment about the initial pure epoxy specimen (Figure 2).

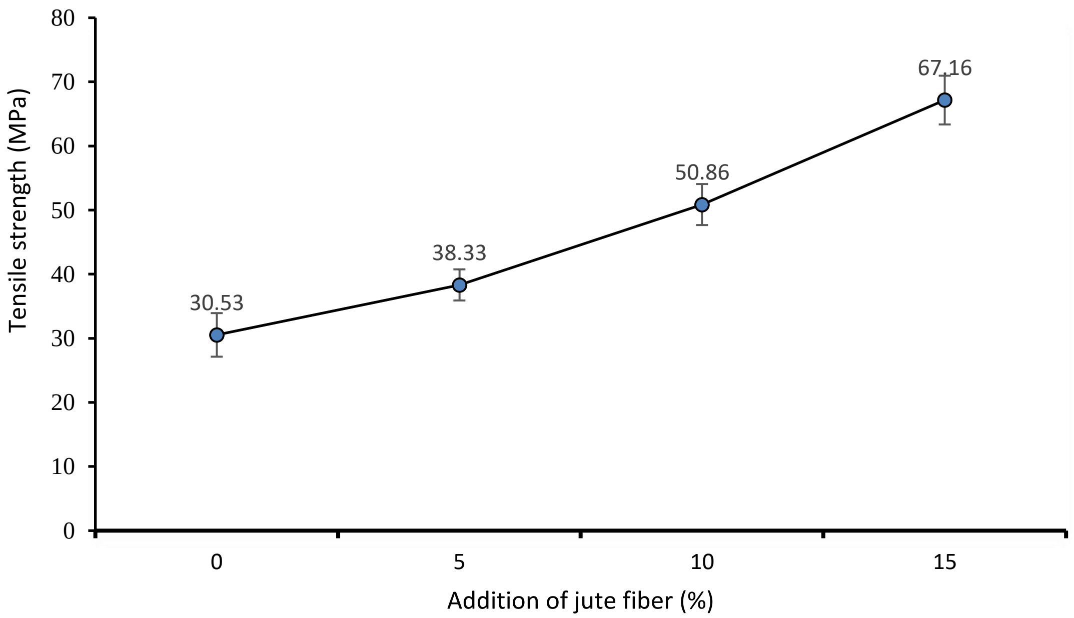


Fig. 2. Average tensile strength of the samples with change of fiber percentages

The increased proportion of fibers significantly enhances the reinforcement of the composite material. Jute fibres' inherent strength and rigidity make them suitable reinforcements when incorporated into a composite. The material's strength is enhanced by increased fiber content, resulting in a greater number of load-bearing fibers that effectively resist applied tensile forces. Moreover, the augmented quantity of fibers enhances the distribution of load by dispersing it across a wider surface area and mitigating stress concentrations. Furthermore, the heightened fiber content enhances the fiber and matrix interaction, facilitating effective stress transmission and augmenting the load-carrying capability. The increase in the proportion of jute fiber in the composite material leads to a corresponding increase in the overall tensile strength due to the combined effects [31-32].

3.1 Effect of water absorption

Natural fibers exhibit high porosity and possess a propensity to absorb water readily. The phenomenon of swelling in composite materials occurs due to the absorption of water by the fibers. Swelling may damage a composite material's structural integrity and weaken the bond between the fiber and matrix. This phenomenon possesses the capability to influence the properties and performance of diverse materials. Swelling can result in composite materials' fiber-matrix interfaces losing structural integrity and mechanical strength [33]. The rate of water absorption by the samples is shown in Table 2.

Table 2
The water absorption rate of the different samples

Time (Days)	Epoxy	Epoxy+ 5% Jute Fiber	Epoxy+ 10% Jute Fiber	Epoxy+ 15% Jute Fiber
0	0	0	0	0
3	0.61	4.85	6.2	7.025
6	0.68	5.26	6.6	7.76
9	0.77	5.5	6.8	8.125
12	0.8	6.15	7.1	8.425
15	0.83	6.58	7.5	8.925
18	0.84	6.61	8	9.325
21	0.85	6.65	8.3	9.525
24	0.87	6.66	8.5	9.825
27	0.88	6.67	8.6	10.125
30	0.88	6.68	8.65	10.425
33	0.88	6.69	8.8	10.555
36	0.88	6.69	8.84	10.605
39	0.88	6.7	8.86	10.585
42	0.89	6.7	8.86	10.605
45	0.9	6.75	8.91	10.61
48	0.9	6.765	8.92	10.615
51	0.89	6.765	8.92	10.616
54	0.89	6.77	8.92	10.617
57	0.89	6.8	8.93	10.608
60	0.9	6.8	8.94	10.608

Figure 3 depicts the correlation between the proportion of fibers in various samples and their respective water absorption rates. Pure epoxy exhibits hydrophobic properties, resulting in a minimal moisture absorption rate over a 60-day duration due to the porosity presented in the epoxy sample [34]. Upon adding 5% jute fibers to the epoxy, there was a gradual increase in the moisture absorption rate over several days, followed by a stabilization of the absorption rate. Incorporating jute fibers at a concentration of 10% yields comparable outcomes to those observed with 5% jute fibers, albeit with a higher degree of moisture uptake. The sample with a 15% addition of jute fibers exhibits the highest moisture absorption rate (Figure 3). The moisture absorption rate of this sample exhibited a gradual increase that surpassed that of the other samples, and this trend persisted over time.

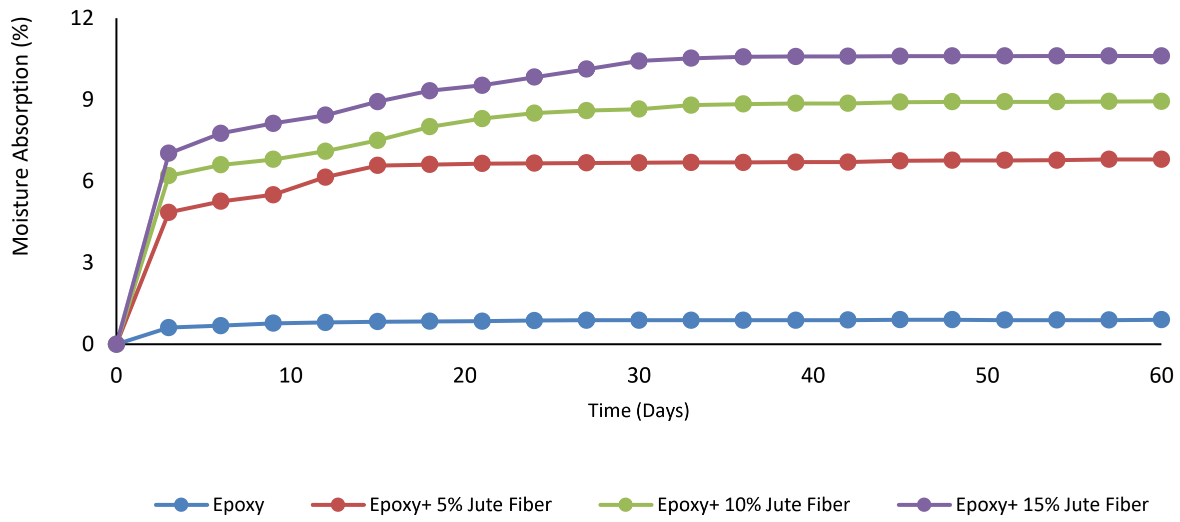


Fig. 3. Moisture absorption rate for different samples

Numerous factors affect the moisture absorption rate in composite materials, including the amount and existence of jute fibers. The greater surface area of natural fibers compared to the matrix material facilitates the interaction and absorption of water molecules. The incorporation of jute fibers into the composite material resulted in an enhancement of its surface area and moisture absorption capabilities. The bonding between the matrix and fibers is affected by the water absorption of the jute fibers [34]. In cases where the contact between the fiber and matrix is inadequately sealed or bonded, there is a possibility for moisture ingress and subsequent absorption. Porous characteristics are exhibited by fibrous natural fibers such as jute. These pores can absorb water. The incorporation of jute fibers in the composite material results in an increase in porosity, thereby facilitating the ingress and absorption of water [35].

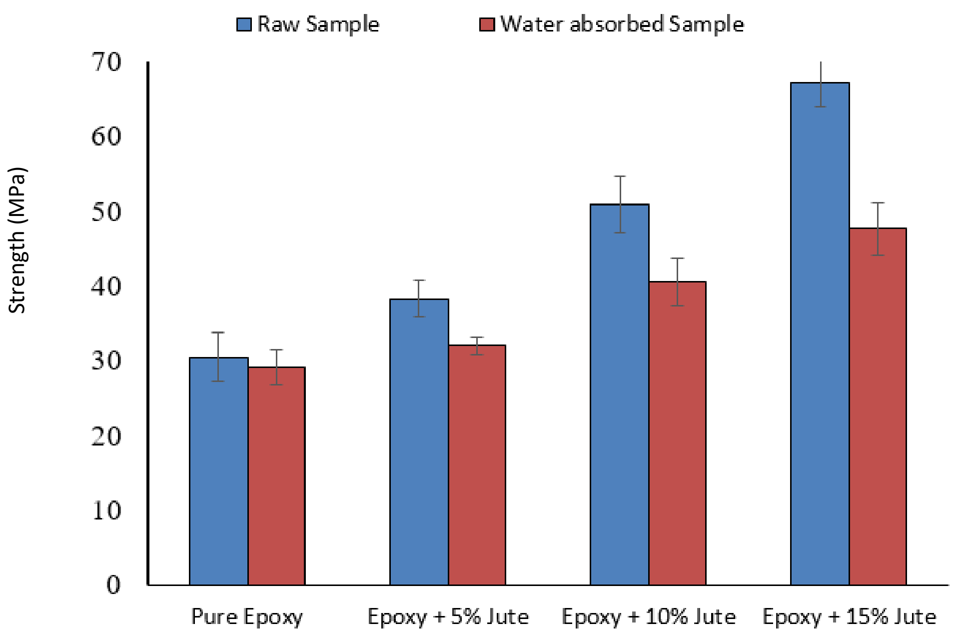


Fig. 4. Comparison of tensile strength between raw samples and water-absorbed samples

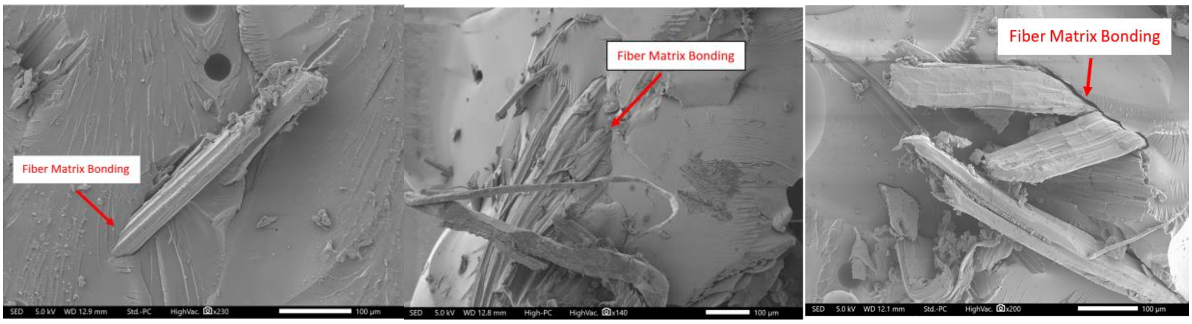
Since natural fibers are hydrophilic, the binding strength between the fibers and the matrix is reduced when exposed to water. The impairment of fiber-matrix adhesion due to moisture decreases load transmission and other advantageous mechanical characteristics of composite materials are shown in Figure 4. The prolonged exposure of natural fibers to moisture results in their deterioration. The process of hydrolysis results in the breakdown of both the fiber and matrix constituents. The composite's mechanical characteristics and durability have been compromised [36].

Figure 4 shows that the strength of the weathered pure epoxy was not degraded due to the hydrophobic nature of the epoxy. However, the strength of 5% jute fibers was weakened. When the percentage of jute fiber in the material rises to 10% and then 15%, the strength drop becomes more obvious. Hydrolysis, caused by absorbed water, weakened the fibers and reduced their mechanical characteristics, lowering the composite's strength [37-38].

3.2 Fracture surface of the raw and weathered samples

The fracture surface morphology presented in Figure 5 of the jute fiber composites undergoes alterations, exhibiting an increase in roughness, swelling of its fibers, and the formation of aqueous cavities or channels due to the absorption of water by the fibers. The weakened interaction between the fibers and the matrix reduces adhesion and increases the probability of debonding or separation [38]. The comprehension of these modifications and the impact of water absorption on the composite specimens can be facilitated through the utilization of scanning electron microscopy (SEM) images.

The SEM images presented in Figure 5 illustrate a noteworthy degree of bond between the fiber and matrix in both composite variations. The SEM images of the fractured surface indicate that the jute fiber maintains a sturdy and unmodified appearance. This type of bonding facilitated the transfer of load from the matrix to the fiber, resulting in a significant enhancement of strength [39].



(a) (b) (c)

Fig. 5. Fracture surface of (a) 5% jute fiber raw composite, (b) 10 % jute fiber raw composite, and (c) 15% jute fiber raw composite

Voids or interstices within jute fibers provide conduits for water infiltration when immersed in water. Inadequate sealing or protection of composite materials may result in the infiltration and occupation of these voids by water molecules [39-40]. The potential displacement of the composite matrix due to water absorption may result in discernible alterations of the fiber. This water absorption by fiber created more voids in the composites found in Figure 6. The higher the fiber percentage, the more voids are noticed in the SEM images. The large cavities are visible for the 15% jute fiber composite than the 5% and 10% fiber-added composites. The phenomenon of interface weakening results in debonding or separation of the fiber from the matrix, thereby reducing the composite material's overall strength.

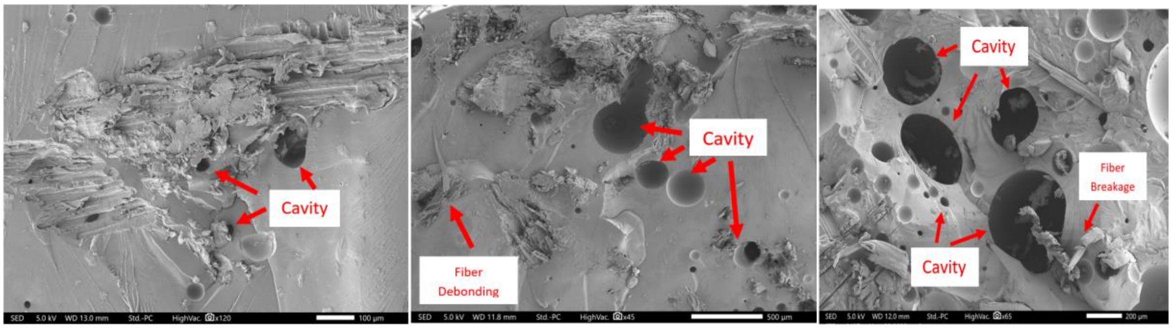


Fig. 6. Fractured surface of water-absorbed composite samples of (a) 5% jute fiber composite; (b) 10% jute fiber composite, and (c) 15 % jute fiber composite

4. Conclusions

The principal purpose of this study was to inspect the impact of jute fibers on moisture absorption and its consequential effect on the mechanical tensile characteristics of composite materials comprising epoxy resins. The results of comprehensive experimentation indicate the following discoveries. Incorporating long jute fibers, at varying percentages of 5%, 10%, and 15%, into epoxy-based polymer results in a corresponding increase in the material's strength by approximately 26%, 67%, and 120%, respectively. The augmentation of the percentage of jute fibers has been observed to enhance the crack propagation resistance and improve strength. The research revealed that water immersion reduced the potency of pure epoxy by 4%. The 5%, 10%, and 15% jute fiber composites exhibited strength reductions of 16%, 20%, and 29%, respectively. These reductions were attributed to the swelling effect caused by moisture absorption and the debonding of fibers from the matrix. A higher percentage of fiber resulted in increased water absorption and greater degradation of tensile properties due to the hydrophilic nature of fibers. The SEM image of the raw samples demonstrated a robust bond between the jute fiber and matrix, resulting in enhanced strength. Upon moisture absorption, the SEM image revealed considerable damage to the composites, characterized by numerous large cavities, fiber, and matrix debonding. These factors collectively contributed to a reduction in the strength of the weathered sample when exposed to water.

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