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Research article

Effect of alkali treatment on mechanical and water absorption properties of biodegradable wheat-straw/glass fiber reinforced epoxy hybrid composites: A sustainable alternative for conventional materials

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A R T I C L E I N F O

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A B S T R A C T

Fiber-reinforced polymer composites are preferred over conventional materials because of their superior strength and modulus. Previously limited due to high manufacturing costs, synthetic fibers have been replaced by some natural fibers, such as waste wheat straw fibers. Here, epoxy-based polymer composites' mechanical and physical properties have been investigated, focusing on fiber weight ratios for both treated and untreated fiber. The research found that treated fibers display more effective mechanical qualities than untreated fibers, with a higher tensile strength of 54.4 MPa. The untreated Wheat Straw-Glass fiber reinforced composite has a less tensile strength of 26.3 MPa (10 wt% fiber). Pure resin-based composite has the most minor tensile strength at 1.52 MPa. The highest flexural strength obtained for hybrid composite is 88.76 MPa for treated fiber with epoxy resin and 49.6 MPa for untreated 30 wt % fiber. At the same time, the sole epoxy resin composite has the lowest value of 10.60 MPa. Untreated fiber (30 wt%) has the highest impact energy of 8J. Untreated wheat straw fiber absorbs more water due to its hydrophilic nature. In contrast, treated fiber exhibits better bonding and minimal water content, and the sole epoxy resin composite exhibits hydrophobic properties, resulting in less water absorption. The treated fiber displays better bonding than the untreated fiber throughout the SEM analysis. Wheat Straw fiber is mainly used for biodegradable plastic formation, housing construction, building materials, etc.

1. Introduction

Fiber-reinforced polymer composites are preferred over conventional. In the past ten years, natural fiber-reinforcing epoxy composites (NFREC) have attracted a lot of attention because of their exceptional mechanical qualities, including accessibility, lightweight, low density, rigidity, affordability, and biodegradability [1–4].

Numerous engineering applications in vehicle, military, railway, home decorated furniture, and building engineering have been made possible by the uncontrolled development of natural reinforcing hybrid composites [5,6]. Natural fiber reinforcement mostly used biodegradable materials. So, necessity of fiber-reinforcing composites has greatly increased [7]. These natural fibers are

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frequently mixed with various synthetic fiber types during the hybridization process for two reasons. First of all, the mechanical characteristics of natural fibers are less than those of synthetic fibers. So, natural fibers are mixed with synthetic fiber to enhance the strength of composites. The second step, they are more vulnerable to water damage because of their hydrophilic characteristics [8]. It may be used to reinforce concrete by adding reinforcing materials. Epoxy resin can be used in several applications and exhibits excellent thermal, mechanical, and chemical-based along with corrosion-resistant properties [9]. It also cures with little shrinkage. The length of fiber, weight ratio, fiber initial alignment, with adhesion between the interface fibers as well as matrix are factors which impact a composite's mechanical attributes [10–12]. Scientists and researchers working with polymeric composites are now heavily concentrating on inventing suitable tree fibers because of the building of interesting fiber-reinforcing polymeric composite materials. A unique Furcraea seller, K. Koch peduncle fiber, was used in the current study to test the efficacy of reinforcement materials. To achieve this, a thorough composite property was performed to establish the appropriate fiber proportion of weight for the best features of the composite.

According to research [13], modifying the surface, such as treatment with chemicals, can enhance the physiochemical along with mechanical capabilities of the biological yarns. According to the literature, several chemical treatment methods exist, such as silane, alkaline, hydrogen chloride, and others [14]. In a recent study, maize stalk fibers were treated with alkaline and silane-alkali. The outcomes described that silane pretreatment enhanced the fiber's interaction with the resin based on coupling characteristics [15]. In a different investigation, palm oil filaments were treated with an alkaline solution, the maleic anhydrate, with silane to postpone the onset of heat degradation [16]. Treatment with alkaline and maleic anhydrate boosted the mechanics. The usage of alkaline-treated fibers of flax in biotic epoxy materials was similar. The results demonstrated that the mechanical characteristics have been enhanced by interfacial bonding [17]. The literature demonstrates that chemical treatment improves a specific fiber property when reinforced with a polymer matrix. Silane processing improves the physiological chemical characteristics of natural fibers compared to other treatments. The coupling feature of silane improves the fiber's adhesion to the matrix [18].

One of the most significant agricultural residues is wheat straw. It is a yearly renewable fiber resource widely accessible and abundantly available. Only a tiny portion of the tons of unutilized wheat straw wastes produced yearly in Canada have been utilized for feedstock and energy production. Given its resemblance to wood, straw is likewise a natural composite material. This is mainly produced with cellulose, lignin, and hemicellulose. Over the past 20 years, straw has drawn interest as a viable fiber for particleboard and paper composites. Plant stem fibers are extracted using various techniques, including mechanical, physical, and steam explosion methods. Retting is a method of managing plant stem deterioration that separates the fiber and woody core, making it easier to recover the fibers through the plant roots. Enzymatic/Microbial retting is among the most widespread practices for generating superior cellulosic fibers from trees used in the agriculture section, namely hemp jute with flax. The enzymes generated by fungi and microbes debilitate or dissolve pectin glue, which holds the fiber bundles together, releasing cellulosic material within the fiber. In this study, we looked into producing wheat straw fibers that may serve as thermoplastic-reinforced materials by ret wheat straw using a fungus removed from the elm tree bark. Fungi regeneration was followed by mechanical defibrillation to generate fibers. Before combining fibers into materials made of composites, their potential for reinforcement must be established via characterization. The physical, mechanical, and SEM attributes of the treated fibers were evaluated and contrasted with those of the wheat straw fibers that had not been treated [19].

Utilizing glass fiber as an advanced glass pile can considerably enhance the efficacy of fiber E-glass, epoxy, and its composite. The performance and characteristics of natural fiber composites decline with time as a result of moisture absorption [20–22]. Longer immersion times and higher fiber contents tend to cause composites to lose their mechanical qualities [23]. Naturally, fiber-reinforcing polymer composites must undergo extensive testing to determine how long they will last when exposed to wet surroundings or immersion into water. This occurs due to the degradation of the material brought on by water infiltration into the polymer, which includes plasticization and swelling and lowers the temperature at which transition occurs, as well as flexibility, including modulus of flexion. Absorption of water minimizes flexural as well as compression abilities [24]. The tribological as well as mechanical qualities of glass, sisal, and jute hybrid composites were investigated [25].

Traditional structural materials can be replaced with composites made of natural fibers that are suitable from an environmental standpoint. Even though many scientists have concentrated heavily on the production of these materials using mats of the basket, plain, and twill type, there is still much space for improvement in the physical and mechanical qualities of composites composed of natural fibers as well as hybrids [10,20–22,26]. Researchers are also concentrating on composites consisting of short fibers. Because most studies focus on twill, plain as healthy basket types of natural fibers, unidirectional mats formed of fiber the yarn were used in this study to examine the mechanical properties. The handloom was mainly used to make unidirectional fiber mats using fiber yarn. Because of its hydrophilic qualities and intermediate strength in mechanical applications when compared with carbon with Kevlar, this kind of composite's (natural fiber) application still has limitations. Furthermore, it is currently unclear how mechanically long-term durability will work in corroded and moist conditions. The main objective of this work is to evaluate the long-time toughness and the impact of mechanical properties regarding the corrosive surroundings of wheat straw-glass fiber hybrid composites using epoxy resin. The treated fiber has improved tensile strength and flexural characteristics due to the application of a 5 % NaOH solution. The whole process was done using a hand layup procedure. As a result, sometimes voids, cracks, etc., are also created, which is responsible for decreasing the strength and, in most cases, unsuitable outcomes.

Hybrid composites made of wheat straw and glass fibers balance durability and biodegradability. Compared to composites made entirely of wheat straw fibers, the glass fibers add durability and strength while slowing down the pace of total degradation. This qualifies them for various uses where material performance and environmental effects are crucial. By utilizing these hybrid composites, industries can still contribute to sustainability while producing products with improved mechanical and shelf life.

While the hand lay-up process is a flexible and affordable way to create hybrid composites, such as composites made of wheat straw and glass fiber, its uniformity and void content are limited. The quality and performance of the composites can be improved by innovations like vacuum bagging and alternative processes, including RTM, compression molding, pultrusion, autoclave curing, and prepregs. With more control over the fabrication process, these techniques produce composites with improved mechanical qualities and less void formation.

1.1. Materials and composite preparation

Waste wheat straw fiber collected from village areas is available in Bangladesh and may be utilized as a substitute for artificial reinforcements collected from wheat straw fields. Additionally, 450 GSM of chopped randomly oriented glass fibers are used. The hardener (HY 951) and the epoxy resin (LY 556) can be bought from the technical shop in Dhaka, Bangladesh. On the contrary, grease surface plate, weight machine, load, etc., are also used for fabrication and are available at the Khulna University of Engineering & Technology, Bangladesh lab. The strength of fiber-reinforced epoxy composite (FREC) is significantly affected by the configuration of the fiber mat as well as the weight ratio of the fibers. The free mat might be built in a limited number of bundles rather than one fiber. To manufacture the unidirectional natural fiber mat utilizing wheat straw fiber, the present research developed a manual loom that was notably scaled. The handloom's schematic design, the mat's design, the woven unidirectional natural fiber, the wheat straw fiber, as well as the glass fiber flooring are all depicted in Fig. 1(a–d).

1.2. Alkali treatment

Wax, oil, and other impurities will be eliminated from the collected wheat straw fiber by treating it with 5 % NaOH for 6 h. Following a thorough rinse with distilled water to reduce impurities, the fiber is dehydrated in an oven for 4 h at 70 °C. NaOH (EMPLURA brand) in overabundance turns the fiber brittle. More Effective composite cannot thus be formed. To treat with alkali, 4–5% NaOH is implemented. Because 5 % NaOH is so good at altering fiber surfaces to improve interfacial adhesion with the matrix while preserving fiber integrity, it is a popular option for alkali treatment. The effectiveness of the treatment, the mechanical characteristics of the fibers, and the overall performance of the composite material can all be significantly impacted by altering the concentration of NaOH. In specific applications, obtaining the desired results requires careful optimization and experimental confirmation.

1.3. Composite fabrication process

In order to create hybrid composites which are fabricated with epoxy, a traditional hand lay-up method is utilized, and then the substance is carefully compressed and molded. There are mainly two types of fiber used in this experiment; they are Glass fiber and Wheat Straw fiber. The weight ratio of wheat straw to glass fiber is kept constant at 1:1 [27,28], and composites are mainly made with three different weight percentages of loading of fiber (10 wt %, 20 wt %, 30 wt %). To create a balanced composite material that provides a fair trade-off between mechanical performance, cost, weight, and environmental sustainability, wheat straw and glass fiber were weighed out at a ratio of 1:1. Although it involves inevitable trade-offs, adjusting this ratio helps better customize the composite's qualities to match the needs of a given application.

Table 1 shows the Classification and Constituents of fiber Epoxy-resin-based wheat straw/glass fiber hybrid composites. The suggested ratio of epoxy to hardener HY951 for epoxy-based composites wide range of composites made with epoxy and other common hardener volume ratio are 10:1. Fig. 2 shows the unidirectional wheat straw/glass fiber hybrid composite.

The composite shown in Fig. 2 consists of three layers of glass fiber as well as two layers of wheat straw fiber. Plastics are usually used as the mold release sheet which is applied in both top and bottom of the mold surface during fabrication. It is essential to take precautions during preparation to prevent the introduction of air bubbles. For 48 h at room temperature (30 °C), mold is subjected to a mild pressure of 120 kg from above. The samples are removed from the mold after 48 h and then cut to the appropriate size with a cutter machine to prepare the sample for physical and mechanical testing. Similarly, the fabrication for the untreated wheat straw fiber and glass fiber was also done. The total process of the composite was done using the hand layup technique which is shown in Fig. 3. Thus, sometimes, many voids are created. Therefore, many cracks were made in the final sample.

(a) (b) (c) (d)

Fig. 1. (a) Handloom; (b) Wheat-Straw fiber; (c) Glass fiber; (d) Epoxy resin and Hardener.

Table 1
Discovering and collapsing the constituents of epoxy resin-based hybrid composites that feature continuous typical mechanical characteristics of hybrid composites [29].

Composites designation	Composition for the composite,%	Young's modulus (MPa)	Poisson's ratio, ν	Elongation (%)	Density, ρ (kg/m3)
Treated fiber	10 % fiber+90 % resin	1250	0.32	4.08	4861
	20 % fiber+80 % resin	1140	0.45	3.39	5283
	30 % fiber+70 % resin	1190	0.49	3.12	6378
Untreated fiber	10 % fiber+90 % resin	517	0.22	6.99	3009
	20 % fiber+80 % resin	573	0.27	6.15	4621
	30 % fiber+70 % resin	1020	0.36	4.69	5103
Pure resin	100 % resin	87	0.21	0.69	952

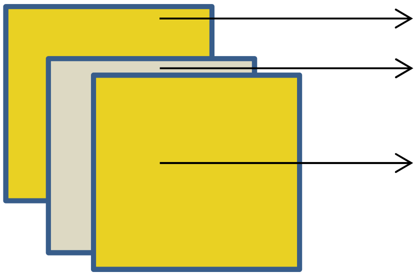

Fig. 2. Stacking sequence for Wheat-Straw/Glass fiber reinforced with epoxy resin based hybrid composites.

1.3.1. Base sample preparation (100 % matrix)

The hardener and the epoxy resin were mixed into a mold box to make the base sample. In this process, the fiber and the matrix ratio is 10:1. After that, it was stored in the mold box for two days. After two days, the sample had detached from the mold box. After that, it was cut into different sizes for testing according to ASTM standards.

$$\text{Poisson's ratio}, \upsilon = -\frac{d€\ \text{trans}}{d€\ \text{axial}} \quad \text{(Equation 1)}$$

Here, ʋ = Poisson's ratio; d€ trans = transverse strain; d€ axial = axial strain.

In this Table 2, the ASTM standard is described for several mechanical tests. The different samples' lengths, widths, and thickness are also mentioned.

2. Results and discussion

2.1. Tensile test

Tensile testing was done with a specimen shaped like a rectangle. The tensile test, which had dimensions of 250x19 mmˆ2, a procedure compliant with ASTM D3039, was used. The samples' thickness varied depending on the kind of materials and how many mats were used to make the composite plate. With a crosshead speed of 30.0 mm/min,0.001 N pretension, and a 100 kN load cell, a Testometric universal testing machine M500-100CT was employed.

The experiment was place at a temperature of 30 °C. Fig. 4 depicts the specimen geometry and the way the samples were clamped into the UTM apparatus. Each kind was evaluated on a minimum of three samples. The Wave Maker automatically determined the percentages of elongation, Young's modulus, maximum strength, and tensile strength [29].

From Fig. 5(a–f), it is demonstrated that, treated fiber contains lower strain value than untreated fiber [27]. Because some processes can make the fiber surface stiffer, reduced strain values can result from the fiber's reduced ability to flex or extend under load due to this higher stiffness at the fiber surface. Lower strain values result from this stiffness, which can boost tensile strength while limiting the material's total capacity to flex and absorb energy. However, improved bonding between fibers and matrix material enhances load transfer, preventing deformation and elongation, resulting in lower strain values and preventing fiber-matrix deboning or pull-out. Moreover, Brittle materials experience less plastic deformation before failure, resulting in lower strain values and more fragile fibers and composite materials.

According to Table 3, fiber that has been subjected to 30 wt % exhibits a greater tensile stress (54.4 MPa) than 20 wt % or 10 wt % respectively. So, tensile stress increases with increasing fiber content, and there are some reasons for this behavior. First of all, fiber strength [27]. Typically, fibers exceeded matrix material in strength. The composite material improves additional strength when more muscular fibers are incorporated into the matrix, increasing the total quantity of tensile stress the material can endure. Secondly, load distribution. In this case, the composite material's fibers efficiently distribute load due to their high strength, reducing stress on the matrix material and enabling it to handle higher tensile stresses. On the other hand, fibers can increase the composite's ability to stand

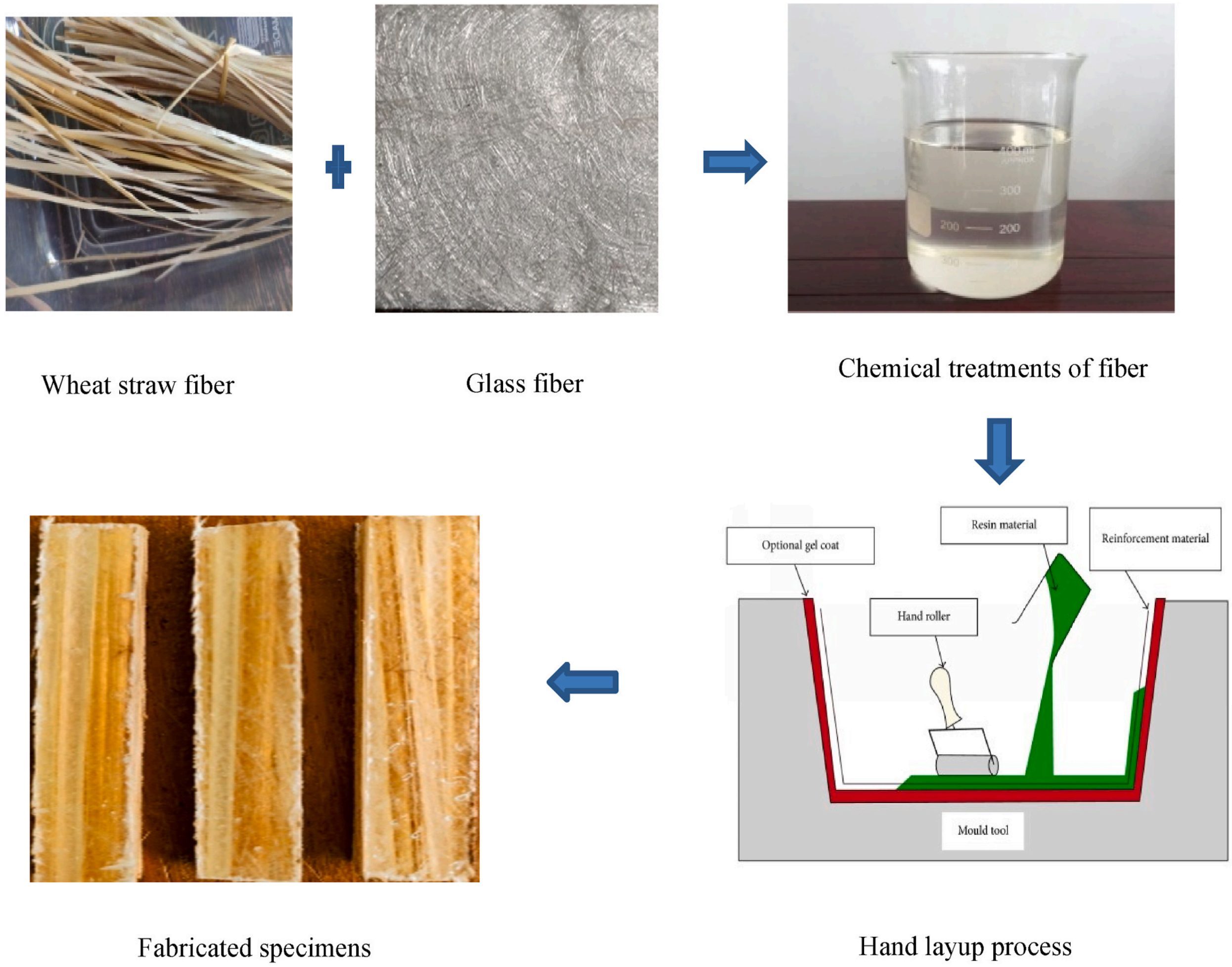

Fig. 3. Graphical abstract of manuscript.

Table 2
ASTM standard, dimension and sample of the wheat straw/glass fiber hybrid composites.

Test	Standard	Length (mm)	Width (mm)	Thickness (mm)	Gauge length (mm)	Sample
Tensile	ASTM D 3039	250	19	5	60	
Flexural	ASTM D 790	127	13	5	70	
Impact	ASTM 4812	65	13	5	–	
Water absorption	ASTM D570-98	60	10	5	–	

up to fracture. Consequently, even if a crack does get started in the material, it may be inhibited or slowed down by the fibers, enhancing the material's susceptibility to snapping under strain. The composite made with pure resin only possesses the lowest strength, 3.10 MPa, because of its low fracture toughness characteristics.

Again. From Table 3 as well as from Fig. 6 it depicts that, the treated fiber contains maximum tensile stress than untreated fiber [30, 31]. Coatings or other processes that promote adhesion between the fiber surface and the matrix material may be utilized when

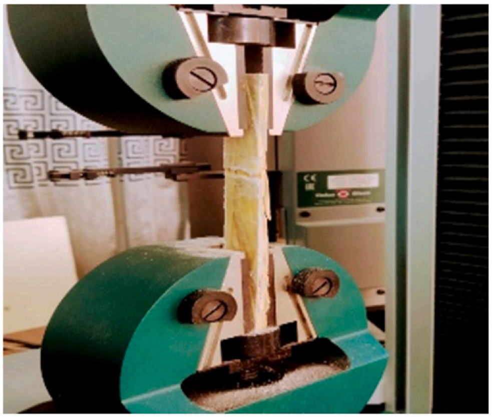

Fig. 4. UTM arrangement for tensile test.

treating fibers. More excellent load transfer within the two materials has been achieved by the increased bonding at the fiber-matrix user interface, which results in a more efficient distribution of stresses. This bonding enhances the composite's total tensile strength by preventing early fiber pull-out or fiber-matrix separation. Because of the enhanced adhesion between the fibers and the matrix, which improves stress transfer, energy absorption, and the overall toughness of the composite, UT30 % samples show better elongation under flexural loading. When the composite is subjected to bending stresses, combining these variables enables it to show higher strain before failure than other loading conditions.

$$\text{Standard error}, \varsigma = \left(\frac{\mathcal{E}(Xi-\mu)^2}{N}\right)^{0.5} \tag{2}$$

Here, ς = population standard deviation; N = the size of the population; Xi = each value from the population; μ = the population mean

From Fig. 7 the error for the tensile stress is 5 %. which is done with laboratory tensile test device. Here, 30 wt% treated fiber shows the highest tensile stress, and 10 wt% untreated fiber shows the lowest.

A thorough error analysis reveals that considering the contributions from production processes, testing uncertainties, material variability, and measurement mistakes, the 5 % error that was initially stated is an acceptable estimate. This comprehensive viewpoint aids in comprehending the consistency and dependability of the attributes of the composite material and can direct modifications to testing procedures to lower overall error.

2.2. Flexural test

The flexural strength in the order of composites involving treated and untreated wheat straw fiber composite was assessed using the three-point bending technique. ASTM D790 states that the test was conducted. The research study was run thrice to obtain outcomes for every composite category. With a 70 mm span length, the frequency of the crosshead was 5 mm/min during flexural tests. The three-point bending test was successfully carried out, model number 25ST, using the Tinius Olsen universal measurement device (Fig. 8). The test adhered to ASTM D790's specifications for span size [29].

From Fig. 9(a–f) it depicts that strain rate decreases with increasing fiber treatment. Here, graph (e) represents the highest strain rate which is approximately 18 as well as it is 20 wt% untreated fiber. On the other hand, ten wt.% treated fiber (Graph (a)) contains a lower strain value, which is not as large as the value 4. The reason is that ductile property. The untreated fiber is more malleable than the treated fiber, and the fiber becomes more brittle when treated with NaOH solution [27]. The ductile material can elongate more than the brittle material. Sub-figures (d) and (e) have a vertical shift because the machine's gripper has slipped.

From Fig. 10 and Table 4 it is represented that flexural stress boosts with enhancing the fiber loading. Here, 30 wt% of treated fiber contains the highest flexural strength (88.76 MPa) compared to other types of composites. Again, ten wt.% untreated fiber has the lowest strength, 35.43 MPa. Tensile and flexural strength are firmly connected, particularly on the tensile side of the bending beam. The strength of the fibers is passed to the composite material since they are typically significantly more potent in tension than the matrix material. Higher flexural strength results from the composite's increased total tensile strength, which fiber loading enhances. As in this experiment, tensile strength increases with raising the fiber content, so flexural strengths are also boosted for the same reason. On the contrary, because of better adhesion properties, treated fiber possesses more flexural strength than untreated fiber [31]. Several factors that strengthen the interfacial connection between the fibers and the matrix can be implicated in the enhanced adhesion between the fibers and the matrix post-treatment, such as surface modification, chemical bonding, removal of impurities, etc. For the flexural test, there is a mismatched the value between Fig. 10 and Table 4. For 30 wt% treated fiber the table shows the highest flexural strength but from Fig. 10 the 20 wt% along with 30 wt% treated fiber are almost same. This is created because of the hand layup procedure. Appropriate outcomes were sometimes not found because the composite was fabricated with the hand layup technique. So, some mismatches are created between the stress and strain data. The stress-strain data obtained from 30 wt% treated fiber are not

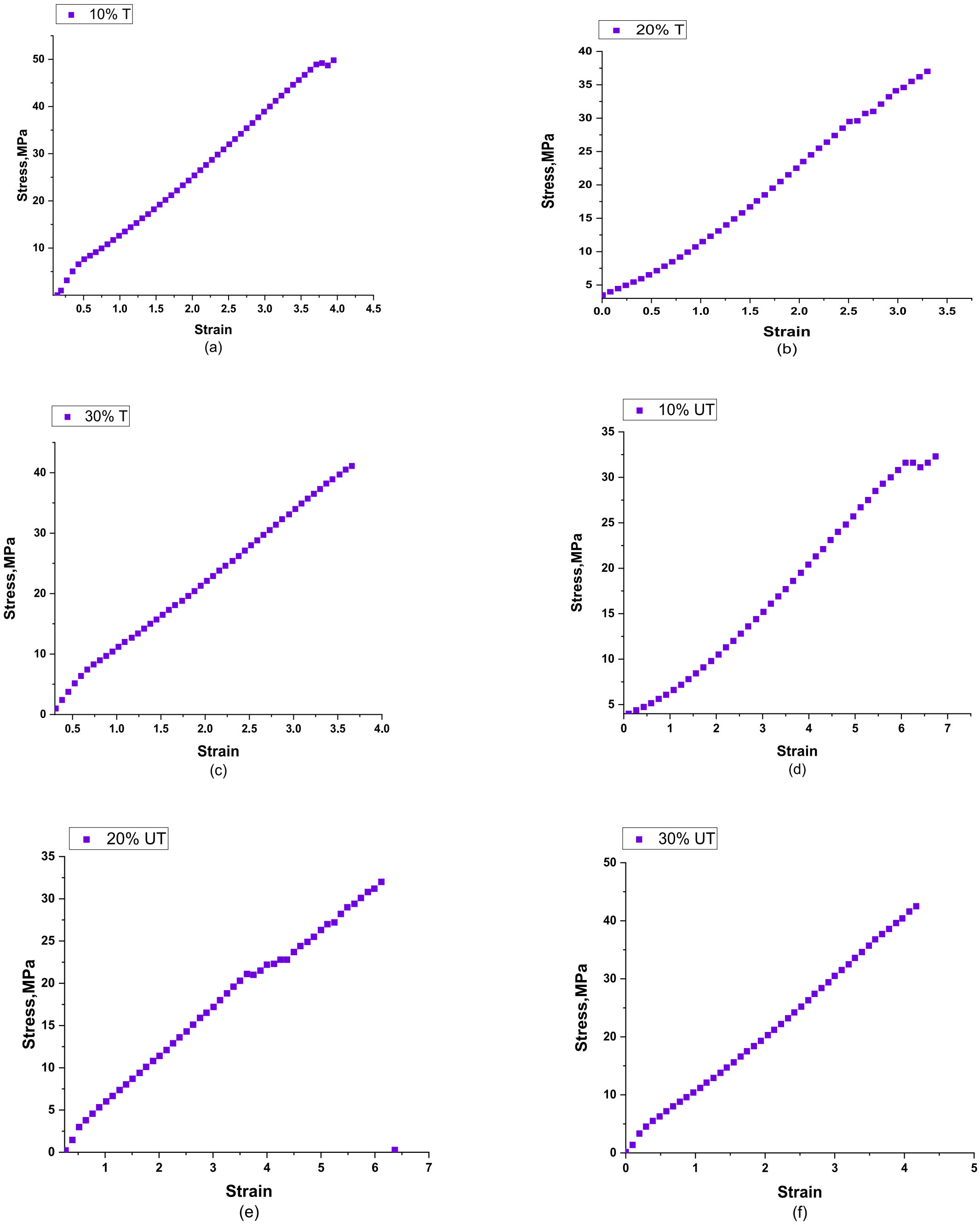

Fig. 5. Stress vs., Strain curve for (a) 10 % treated fiber; (b) 20 % treated fiber; (c) 30 % treated fiber; (d) 10 % untreated fiber; (b) 20 % untreated fiber; (c) 30 % untreated fiber.

accurate.

From Fig. 11 the error for the flexural stress is 5 %. which is done with laboratory flexural test device. Here, 30 wt% treated fiber shows the highest flexural stress as well 10 wt% untreated fiber shows the lowest flexural stress.

2.3. Impact test

When subjected to an impact force, impact energy is needed to break a standard test piece. The composite samples undergo instrumented low-velocity impact testing. The Charpy impact tester is used to conduct the test, per ASTM standard 4812 which is shown in Fig. 12(a and b). The test is complemented by unnotched specimens that measure 65 mm*13 mm*5 mm. An impact testing

Table 3
The values for the tensile strength along with different weight percentages of fiber.

Composite type	Weight % of fiber	Tensile Strength, MPa	Standard deviation (SD)	Confidence interval
Treated fiber	10 %	42.9	2.84	95 %
	20 %	45.4	3.79	
	30 %	54.4	7.19	
Untreated fiber	10 %	26.3	3.45	
	20 %	36.3	0.35	
	30 %	39.1	1.40	
Pure resin	100 % resin	3.10	0.9	

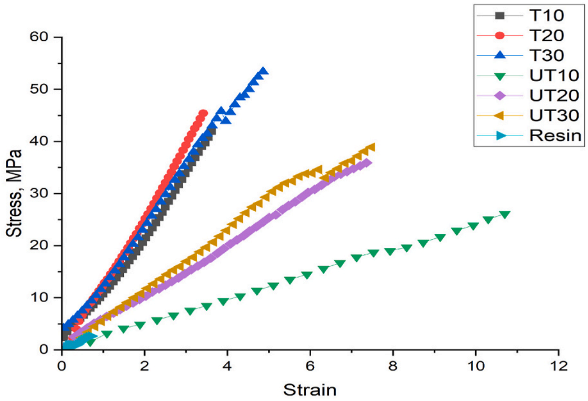

Fig. 6. Stress vs. Strain curve for tensile test.

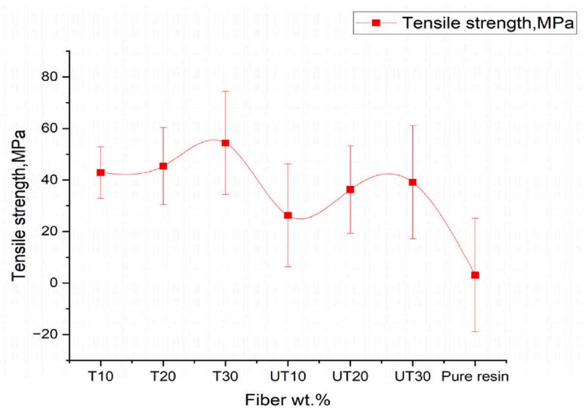

Fig. 7. Error graph for tensile stress.

machine uses a pendulum hammer to shatter a specimen, measure the energy used about the specimen's cross-section, and calculate the material's impact strength. The quantity of impact energy required to rupture the hybrid composite specimen is displayed graphically on a dial gauge.

From Fig. 13 and Table 5, it is shown that, 30 % untreated fiber contains the highest impact energy that is 8J. Here, untreated fiber contains higher impact energy compared to treated fiber. Because, depending on their nature, untreated fibers may behave more ductility than treated fibers. Before fracture, ductile materials frequently experience plastic deformation, which can absorb more energy during impact events. Specific treatments may cause treated fibers to stiffen or become more fragile, lowering their capacity for prolonged plastic deformation and impacting energy absorption. Again, it is seen that impact energy increases with increasing fiber loading. In that case, contact area and toughness increase [31]. The large contact area typically reduces the stress concentration and thus enhances the impact energy. Impact energy can also be described with SEM image analysis. When the incidences of fiber pull-out were counted for the treated and untreated composites at each weight fraction, it was found that untreated Wheat Straw fiber-epoxy composites made with resin had a higher incidence of dietary fiber pull-out than the treated Wheat Straw fiber-epoxy composites composed with resin. An epoxy resin's impact fracture surface showed a smooth fractured surface. Lower fiber-matrix attachment

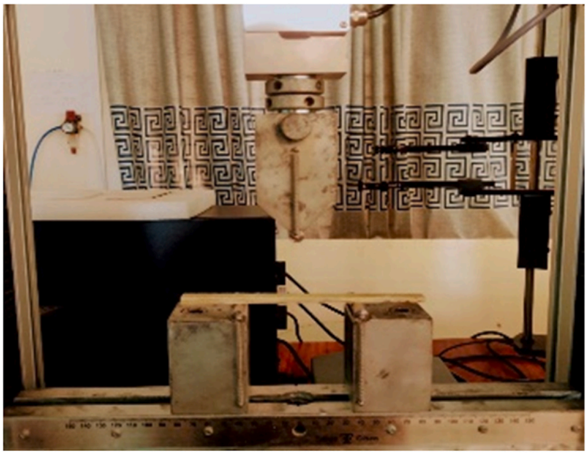

Fig. 8. UTM arrangement for flexural test.

(Fig. 15(f)) is clearly indicated by a higher incidence of fiber pull-out. Lower adhesion between surfaces causes the matrix to absorb more of all available energy applied to a composite than would be the case with more adhesion between surfaces (Fig. 15 (a)), which results in lower impact energy and a matrix with reduced fracture toughness [32]. Because of their rougher surfaces and more microstructural imperfections, which cause friction, deformation, and interfacial debonding to disperse energy, untreated fibers absorb more energy. On the other hand, treated fibers have higher flexural strength because treatments improve surface qualities, decrease flaws, and increase fiber-matrix adhesion, which results in more effective load transmission and resistance to bending stresses. Consequently, Hybrid composites, which include several fibers and matrices, can provide better resistance to environmental elements including moisture, chemicals, and increasing the materials' service life.

2.4. Moisture absorption

Water absorption (WA) % $= \frac{W(t)-W(o)}{W(o)}*100$

W (o) = Weight for dried sample.

W (t) = The sample weight after absorbing water.

%WA = Percentage of water absorption.

21 days were utilized during the water absorption testing.

Finally, from Fig. 14 and Table 6, it can be stated that 5.601 % of the 30 wt% untreated fiber's water absorb the highest amount of water. Natural fibers have a hydrophilic character, which means their capacity to absorb water rises as the loading of fibers does [28]. On the other hand, morphological, chemical, and physical structure all affect how much water is absorbed. The cellulose fiber has a lumen, improving its water absorption capacity. Because of its hydrophobic characteristics, pure resin did not absorb as much water. In this investigation, NaOH was used for alkali treatment. By eliminating hydrophilic substances like hemicellulose and lignin, decreasing surface hydroxyl groups, raising crystallinity, and changing surface roughness, alkali treatment lowers water absorption. Other treatments, which have different methods, prices, and effects on fiber characteristics, include silane treatment, acetylation, benzoylation, and maleated coupling agents. All of these treatments also minimize water absorption and increase fiber-matrix compatibility. The exact needs of the composite material and the trade-offs between processing complexity, cost, and performance must be considered when selecting the best course of action [33].

On the other hand, because the fiber and matrix have higher adhesion properties, the untreated wheat straw with glass fiber composite may absorb more water than the treated wheat straw fiber with glass fiber epoxy resin-based hybrid composites. If a hydrophilic material is subjected to specific surface treatments that stabilize its reactive groups, build protective barriers, and improve fiber-matrix interaction, or if the material has a stable chemical structure by nature, it can exhibit more excellent chemical inertness. These elements combine to create a composite material with the chemical inertness needed for durability and resilience to environmental deterioration and the advantages of hydrophilicity for adhesion. Epoxy-based composites are utilized in maritime structures and boat hulls to stop corrosion from seawater, increasing longevity and lowering maintenance expenses. Epoxy composites are also utilized in construction to stop corrosion and deterioration in bridges and other constructions exposed to hostile environments. The reason for untreated fiber's hydrophilic qualities is that it possesses more chemical resistance than treated fiber. The hydrophobic qualities of treated fiber increase while chemical resistance, including NaOH, HNO3, etc., decreases the sample's water absorption. The non-linear moisture intake behavior noticed in treated fibers is probably caused by hydrophilic groups or surface defects absorbing water quickly, followed by a slower, diffusion-controlled process. The lack of this behavior in UT30 % samples indicate the presence of altered surface properties, improved interfacial adhesion, and fewer microstructural flaws in these fibers, which promote a more even and gradual absorption of moisture. The creation of hybrid composites with bio-based resins and natural fibers (banana, bamboo, etc.) can improve sustainability. These materials have less of an impact on the environment and are simpler to recycle [34,35].

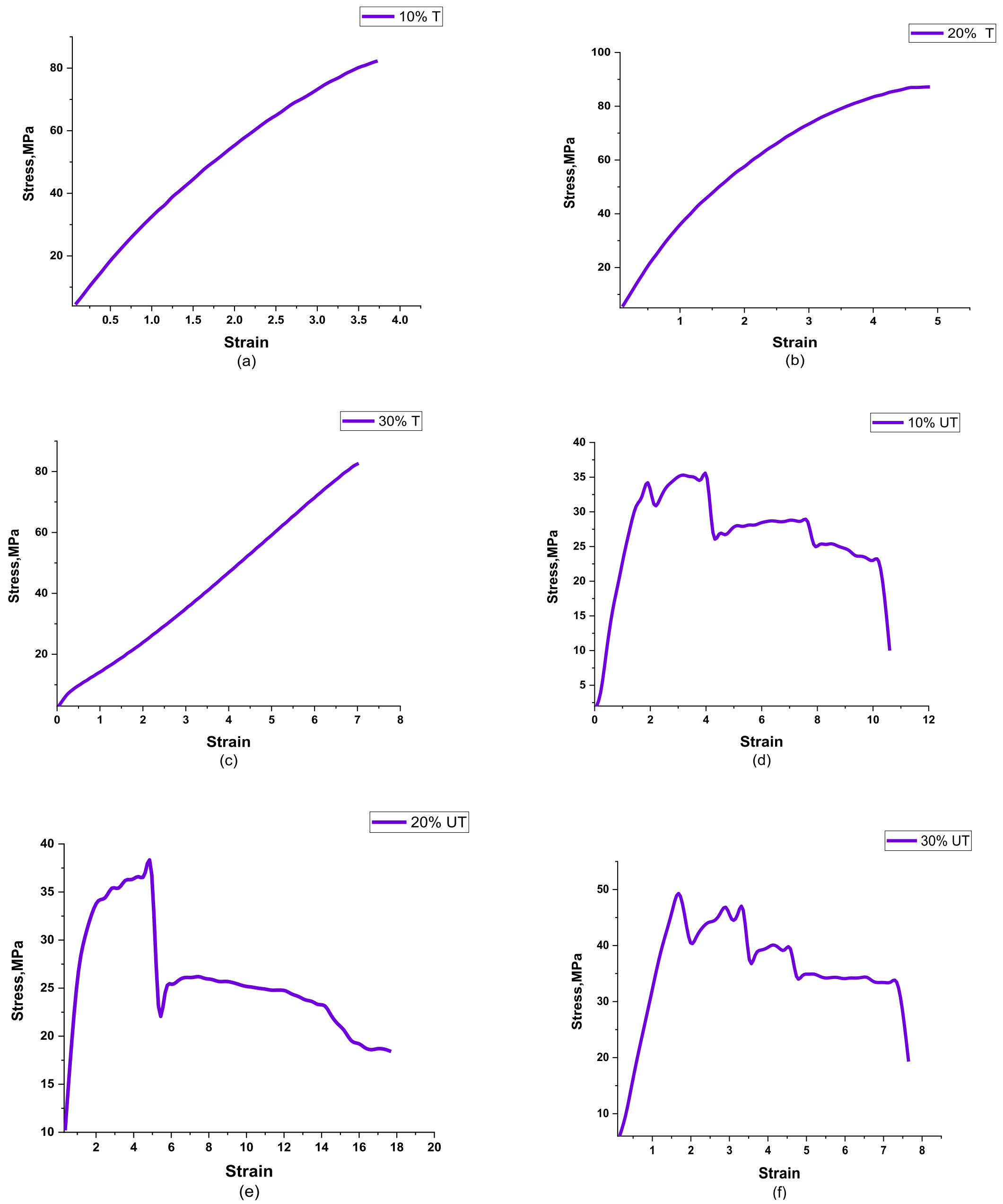

Fig. 9. Stress vs., Strain curve for (a) 10 % treated fiber; (b) 20 % treated fiber; (c) 30 % treated fiber; (d) 10 % untreated fiber; (b) 20 % untreated fiber; (c) 30 % untreated fiber.

2.5. SEM analysis

Scanning Electron Microscope is utilized for the fractographic evaluation. For each form of composite, the microstructure was captured in the SEM. Smaller amounts of voids as well as a fiber to matrix interfacial gaps are shown in Fig. 15(a), indicating that the fiber in 30 wt% treated fiber contains strong cohesion along with matrix. Regions of fiber imprint may be visible in type 20 wt% treated fiber. The matrix region may be seen well, and there is excellent visual cohesiveness within the matrix as well as fibers. Regions of fiber breaking may also be detected in Fig. 15(b). The 10 wt % treated fiber in Fig. 15(c) exhibits a lack of cohesiveness throughout the matrix along with fiber. The aluminum foil was not able to bound to resin along with the interface of wheat fibers as well as the matrix was another sign that there were micro-gaps present. Some visible imperfections, which represent 30 wt% untreated fiber, may be observed in Fig. 15(d). In certain significant areas of the photograph, the fiber breaking region may be observed. It has been found that fibers and the matrix can debond. The interaction within the fiber-metal as well matrix is penetrated by micro cracks, which leads twill

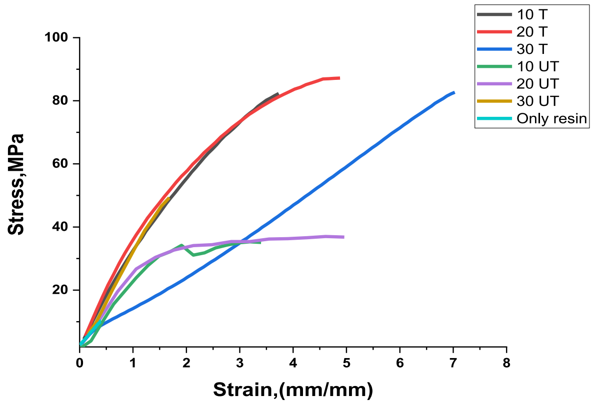

Fig. 10. Stress vs. Strain curve for flexural test (both treated as well as untreated fiber).

Table 4
The values of the flexural strength with different weight percentages of fiber.

Composite type	Weight % of fiber	Flexural Strength, MPa
Treated fiber	10 %	82.78
	20 %	87.3
	30 %	88.76
Untreated fiber	10 %	35.43
	20 %	36.97
	30 %	49.6
Pure resin	100 % resin	10.60

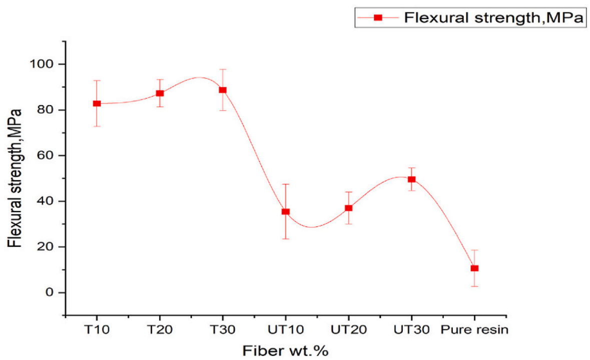

Fig. 11. Error Graph for flexural stress.

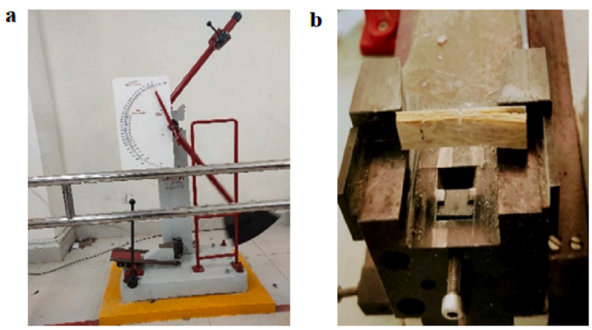

Fig. 12. (a)Impact test machine; (b) Experimental set-up.

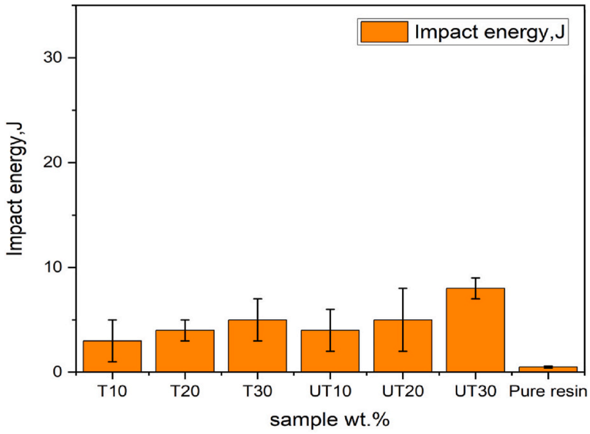

Fig. 13. Impact energy with different weight percentages of fiber (Both treated as well untreated).

Table 5
The values of the impact energy with different weight percentages of fiber.

Composite type	Weight % of fiber	Impact Energy, J
Treated fiber	10 %	3
	20 %	4
	30 %	5
Untreated fiber	10 %	4
	20 %	5
	30 %	8
Pure resin	100 % resin	0.5

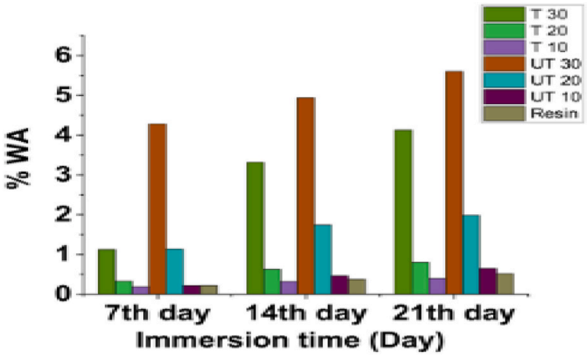

Fig. 14. Water absorption process for both treated and untreated fiber.

as the separation of the composite's layers. The 20 wt% untreated specimens in Fig. 15(e) had a lot of cavities. This quantity of voids was caused by the manufacturing procedure.as well as the 10 wt% untreated fiber with the lowest adhesive bonding, shown by 15(f). It is identified that, in all cases, voids and other cracks are larger in untreated fiber compared to treated fiber. For this reason, treated fiber always contains better tensile and flexural properties than untreated fiber. Again, it can also impact the physical characteristics of the hybrid composite. For example, in the case of water absorption, untreated fiber absorbs more moisture than treated fiber. Because from Fig. 15(e) it is shown that, untreated fiber contains greater number of voids. These voids are the main reason for absorbing water contents.

3. Conclusion

- The study demonstrates that the 30 wt % treated fiber is stronger than the other ten wt.% and 20 wt% fibers. The composite's maximum tensile strength is 54.4 MPa
- The 30 wt% treated fiber's higher flexural strength is attributed to its ability to enhance productive capacity for stress transfer, a quality that is further enhanced by its good resin compatibility. This contrasts the composite made with sole resin, which exhibits

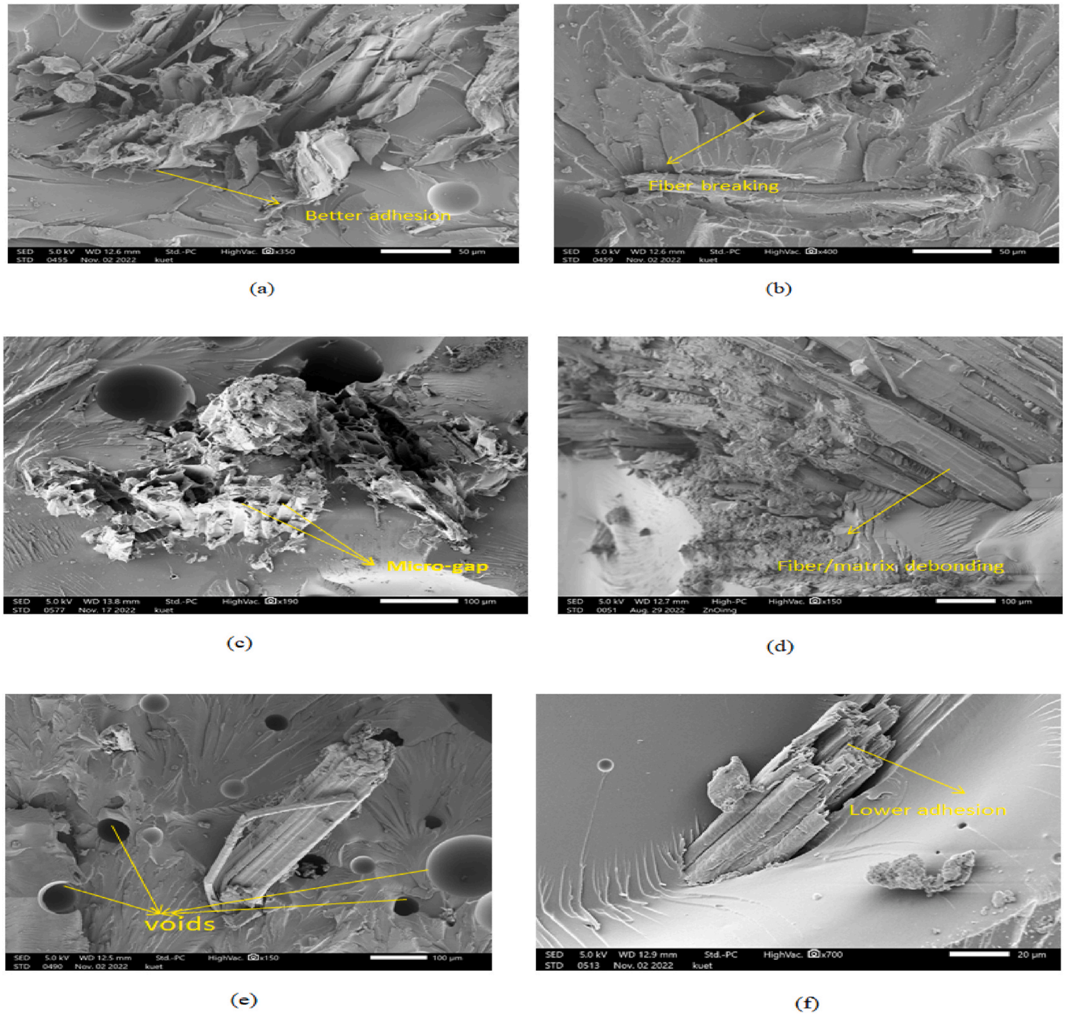

Fig. 15. SEM image analysis for treated and untreated fiber (a) 30 % treated fiber; (b)20 % treated fiber; (c) 10 % treated fiber; (d)30 % untreated fiber; (e) 20 % untreated fiber; (f) 10 % untreated fiber.

Table 6
Changes in water absorption based on immersion duration for epoxy composites reinforcing with the continuous fibers of varying weight percentage.

Composite type	Weight % of fiber	Initial weight W(o),gm.	Absorbed water W(t),gm			%WA		
			7 days	14 days	21 days	7 days	14 days	21 days
Treated fiber	10 %	4.68	4.689	4.698	4.699	0.191	0.383	0.40
	20 %	3.33	3.341	3.355	3.357	0.329	0.745	0.804
	30 %	3.50	3.54	3.633	3.651	1.129	3.661	4.13
Untreated fiber	10 %	3.23	3.237	3.249	3.251	0.216	0.584	0.645
	20 %	4	4.056	4.076	4.081	1.138	1.864	1.984
	30 %	3	3.134	3.17	3.178	4.275	5.362	5.601
Pure resin	100 % resin	5	5.011	5.023	5.026	0.2195	0.457	0.517

the lowest flexural stress. On the contrary, the 30 wt % untreated fiber has a higher impact energy than 10 wt % and 20 wt % fiber. It's possible that breaking the coupling between fibers requires more energy when the fiber loading is higher.

- For every case, it is seen that the pure sole resin composite has the lowest tensile, flexural, and impact values because of the lower fracture toughness.
- It is also seen that 30 wt% in untreated fiber can absorb more water than the ten wt.% and 20 wt% ratio of fiber. On the other hand, the untreated fiber can absorb more water than the treated fiber. Because the natural fiber has hydrophilic properties, for this

reason with enhancing the untreated fiber loading boosts the % of water absorption. However, with alkali treatment, the hydrophobic properties increase.
- Randomly oriented 450 GSM chopped glass fiber is used in this experiment. For this reason, the strength is lower. On the other hand, this experiment is done with the hand layup technique, so voids, cracks, and interlayer delamination occur, which are also reasons for decreasing the sample strength.
- The adhesion within the fiber and matrix is better in treated fiber than in untreated fiber during SEM analysis.
- Wheat straw fiber is used for housing construction and as binding materials, adding to the clay and significantly impacting building materials. Wheat Straw fiber also provides biodegradable plastics. The pioneer in bio-plastic packaging films is Futamura. The "Natureflex" brand is used to produce cellulose films. Additionally, they initially created initially "Futamura owns cellophane" brand.

So, finally it can be said that 30 wt % treated fiber is more applicable for producing biodegradable plastics and building materials because of its effective mechanical qualities compared to untreated fiber. Lower mechanical strength, suboptimal bonding, and moisture sensitivity are the major limitations of this work.

4. Future work

Further research into mechanical characteristics of wheat straw-glass fiber epoxy resin-based polymeric composites could examine features, namely, the effect of orientation of fibers, loading pattern, fiber alignment, etc.

Data availability statement

Data will be made available on request i.e. the datasets generated or analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Silvina Siddika Shifa: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Conceptualization. **Md Mehedi Hasan Kanok:** Validation, Methodology, Investigation, Conceptualization. **Mohammad Salman Haque:** Supervision, Software, Resources, Methodology, Formal analysis.

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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