BenchCouncil Transactions on Benchmarks, Standards and Evaluations 4 (2024) 100183

Contents lists available at ScienceDirect

BenchCouncil Transactions on Benchmarks, Standards and Evaluations

journal homepage: www.keaipublishing.com/en/journals/benchcouncil-transactions-onbenchmarks-standards-and-evaluations/

Full Length Article

Evaluation of mechanical properties of natural fiber based polymer composite

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ARTICLE INFO

Keywords:
Numerical simulation
Jute fiber
Composites
Mechanical evaluation
Optimized fabrication

ABSTRACT

Natural fiber based polymer composites are eco-friendly alternatives to synthetic materials, with greater mechanical properties, biodegradability, availability, ease of access, and affordability. Jute fiber is widely recognized as one of the most important and beneficial natural fibers due to its strength, durability, and biodegradability. In this study, the jute composite is designed and fabricated using a 5-layer jute and epoxy resin, utilizing the manual hand lay-up technique. The combination of 52.5 % jute and 47.5 % of epoxy resin and harder is found optimized to achieve the goals of improving the tensile strength and flexural strength, reducing the cost of epoxy resin, and promoting eco-friendliness and sustainability. Tensile testing was performed on a universal testing machine, while flexural testing was done with a three-point bending test. Experimentally, the composites reinforced with jute and epoxy resin were capable of achieving the required levels of tensile strength (42.91 MPa) and bending strength (69.30 MPa). To validate and visualize specimens, numerical analysis was performed on the ABAQUS simulation software. The numerical simulation utilized ASTM D3039 and ASTM D7264 as the specified requirements for tensile and flexural behavior. For validation, these tensile and flexural test results were then numerically analyzed and compared to the experimental data. Finally, composite design, fabrication, and optimization can improve mechanical properties, reduce composite weight, lower resin cost, and increase sustainability. The proposed design and composition can be implemented to achieve lightweight properties in various applications, such as car components, door handle sheets, bicycle seat backs, and luggage covers.

1. Introduction

A composite is created by combining two or more components with various qualities. Composite materials are created by encasing high load-bearing augmentation in softer materials (matrix). The two critical categories of differentiation of materials are matrix and other is reinforcement. One of the matrix's main roles is transferring stresses between the reinforcing fibers or particles. A composite's mechanical qualities, such as its impact strength, flexural strength, tensile strength, elasticity, etc., are increased when fibers or particles are present. Mechanical and natural damage can also be prevented. The matrix material may be reinforced before or after being inserted into the mold cavity. Undoubtedly, one of the most important advancements in material evolution is the creation of composed fibers with associated models and production methods. Composites are a type of material with unique mechanical and physical qualities that are employed in many different industries. The advantages of composite materials over traditional materials include their tensile stress, impact resistance, bending strength, stiffness, and fatigue appearances. Because of their various benefits, applied in the aerospace sector, advertisement mechanical design systems such as equipment apparatuses, vehicles, diesel engines, and moving parts such as crankshafts, reservoirs, brake systems, compressors, and drivetrains, thermal protection and electronics industries, railway coaches, and aerostructures, etc. [1]. Polymers like thermosets

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https://doi.org/10.1016/j.tbench.2024.100183
Received 22 September 2024; Accepted 1 October 2024
Available online 3 October 2024

and thermoplastics combine with continuous and noncontinuous reinforcements or fillers to create polymer composites. Composites frequently incorporate polymeric materials to improve the material's effectiveness. Polymer composites are being used in an increasing number of technical fields. Jute fiber is entirely renewable and environmentally friendly because it is biodegradable. Due to its golden and silky shine, it is a natural fiber known as Golden Fiber. Usually, worldwide creation, manufacture, and accessibility, along with vegetable fibers, come in second behind cotton. It promotes increased fabric permeability while having a high tensile property and limited adaptability. Jute is, therefore, perfect for packing agricultural items in bulk [2].

Composites with natural fiber compounds are becoming increasingly popular because they can replace traditional synthetic material composites while being more environmentally friendly. The stiffness-to-weight ratio of the resultant composites is improved because natural fibers are lighter than glass fibers, which have a lower density ($q = 1.3$ g/cm^3). The principal stem-type natural fibers that are native to India, Bangladesh, and Nepal are jute fibers, which are also utilized quite extensively. Cotton is the other top producer, followed by jute and related fibers, according to the 2019 World Natural Fiber Production Report [3]. Normally, composite materials can be classified into different types. These types are shown in Fig. 1.

Composite materials, polymers, and ceramics have recently been the most popular developing engineering materials. Organic fiber is popular and environmentally friendly. Natural fiber's obtainable characteristics and simplicity of production have motivated researchers all around the world. They were able to test out locally accessible, less expensive fiber options to see how much they met the criteria for a well-reinforced polymer composite for structural use. Natural fibers were generally employed in composite materials to increase bulk and lower costs as opposed to increasing mechanical qualities. However, the manufacturing and usage of synthetic fibers, combined with environmental issues, have altered the scenario. Historically, both organic and compostable matrices have regularly used natural fibers as reinforcement components. Despite having superior flexural and impact qualities, minor improvements in tensile strength of natural fiber reinforcements have been a focus of research. Numerous initiatives have been made to enhance mechanical characteristics, including the addition of filler and chemical treatment [4]. Like any other natural fiber, jute fiber exhibits natural variability in its exterior and inner mechanical properties; it is influenced by various variables, such as increasing circumstances (such as air temp, moisture, and surface status), 'retting' (fluid, fog, and enzymatic activity) and fiber separation procedures, fiber shape and size, natural substances, and the proportionate amounts of each. The fiber's structural, physiological, and environmental properties are also influenced by the fiber's microstructural features. The overall architecture of the jute fiber is covered in the first part of this section, which is followed by examples of how it performs as fiber, yarn, and woven or nonwoven fabric. To increase its effectiveness for a particular application, jute fiber is functionally treated in some cases. Natural fiber-based goods are drawing a lot of interest from academic and industrial researchers looking to produce sustainable products because of their low carbon footprint. The development of vegetable crops, seed and plant entomology deviation evaluation at various situations, retting process, plant mineral treatment, biological DNA series, and multifaceted of extensively used natural fibers, uses of jute fiber in research and innovation, which would include material for apparel, have recently sparked renewed study interest. Natural, social, and environmental progress are all interconnected and can be directly linked to the rising popularity of jute fibers [5]. In this study, we designed and fabricated the jute composite using a 5-layer jute composite with epoxy resin, utilizing the manual hand lay-up technique. We evaluate the combination of 52.5 % jute and 47.5 % epoxy resin to improve the tensile strength and flexural strength, reduce the weight of the composite, reduce the cost of epoxy resin, and promote eco-friendliness and sustainability. The specimens are tested experimentally utilizing various tests. The evaluation is also carried out using numerical simulation in ABAQUS software.

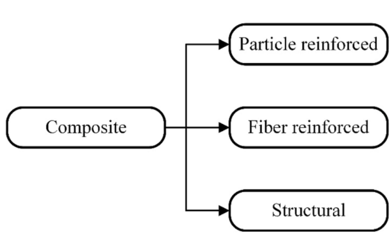


Fig. 1. Identification of composite.

2. Literature review

2.1. Natural fiber-based polymer composites

Natural fibers composites have been increasingly popular in recent years due to their numerous appealing qualities, including biocompatibility, lack of abrasion resistance, adaptability, accessibility, affordability, and ease of production. Researchers have conducted many studies to enhance the mechanical properties of organic nutrient composite materials. Cazaurang et al. investigated henequen fiber's characteristics thoroughly, and it was noted that these fibers had mechanical qualities that make them acceptable for reinforcing in thermoplastic resins [6]. Sweety Shahinur et al. explored that organic, recyclable, and biopolymers are critically needed to replace environmentally hazardous synthetic fabrics from a sustainability perspective. One of the natural fibers, jute, is essential in creating composite materials that have the potential to be used in a range of applications, including home, industrial, and medical devices [5]. Schneider and Karmaker inquired about the mechanical behavior of polypropylene matrix based on jute and kenaf fiber, stating that jute fiber offers superior mechanical qualities to kenaf fiber [7]. Joseph et al. observed fibers, such as silk, pineapple fiber, an empty bunch of fruit fiber from the oil palm, etc., exhibit physical and mechanical activity [8]. George et al. examined how well cellulose fiber performed in polypropylene cellulose composites to increase stiffness and decrease damping [9]. Gowda et al. looked into the physical behavior of jute fiber composites and found that jute fibers composites exhibit larger strengths than those composed of wood [10]. Pavithran et al. reported the fracture energies for polyester composites reinforced with sisal, pineapple, banana, and coconut fibers, and it was observed that except for coconut fiber, an increase in fiber toughness was accompanied by a rise in fracture energy. They also demonstrated the mechanical characteristics of flax/polypropylene composites [11]. Rafiquzzaman et al. employed notched and unnotched specimens to experimentally and quantitatively analyze how composite layering systems behave mechanically. Then, a mathematical procedure incorporating the finite element technique was used to evaluate the overall corrosion behavior of the uniaxial and open-hole polymer thermoplastic composite composites under experimentally applied stress [12]. Aditya et al. found that hybrid FRC composed of Sisal and Pineapple exhibits a higher elastic modulus, whereas FRC with date palm demonstrates enhanced impact strength [13]. Gassan et al. found that the improved quality of the fiber-matrix adhesion reduced the loss of energy on non-penetration impact-tested jute fiber composites [14]. Rajesh et al. found that natural fiber composites using synthetic fiber hybridization can be included in automobile sectors and bullet proof vest [15]. Harish et al. used coir fiber reinforced composite in the mechanical test evaluation and found that coir/epoxy composites exhibit average values for the tensile strength, flexural strength and impact strength of 17.86 MPa, 31.08 MPa and 11.49 kJ/m^2, respectively [16].

2.2. Jute fiber-based polymer composites

The study [3] showed jute fiber characteristics and surface alterations to improve the presentation of their compatibility with the polymer matrices. A survey of jute-based polymer composites is the focus of this paper. The mechanical properties of the various thermosets, thermoplastic, biobased resin, and hybrid jute composites, as well as their composition, are explained. Muhammad Yasir Khalid et al. experimented with the tensile characteristics of hybrid composites reinforced with natural and synthetic fibers. Different glass and jute fiber stacking sequences were used using hand-prepared glass-jute hybrid composites. The experimental findings show that lower jute fiber concentrations were the only ones that had an impact on the tensile characteristics of glass fiber-reinforced polymer [17]. Shahinur et al. observed that chemically treated fibers were found to absorb less heat than untreated fibers. In every instance involving the treated fibers, the heat flow went negative, as did the jute fiber. For the production of composite materials based on polymers, this study offers crucial information regarding the thermal properties of the treated jute fibers [18]. Prasath et al. utilized computer-assisted universal testing machines and charpy impact testing machines, and mechanical properties of manufactured composite plates subjected to tests such as flexural strength and impact strength of the various specimens are estimated. Based on the findings, it can be concluded that a combination of pure basalt fibers retains better values in both flexural and tensile tests [2]. Gupta et al. focused on jute fiber-reinforced polymer composite's mechanical characterization. In this work, the mechanical characteristics of JFRPC—including its tensile, flexural, and impact characteristics—are examined. Additionally, it describes how several factors, including fiber content, fiber size, stacking sequence, and chemical modification, influence the mechanical characteristics of JFRPC [19]. Ovalı et al. established the lack and existence of acrylic acid additions, and the effects of jute fabric surface modifications on the strength properties, flexural modulus, and higher strength properties of the LDPE/jute composites were examined [20]. Ramakrishnan et al. reviewed that for structural applications requiring low to medium strength, jute composite can be a good alternative material. Based on the encouraging findings of the current investigation, it was intended to create green composites and examine their static and dynamic mechanical characteristics [21]. Sakthi et al. studied various mechanical features of fly ash-weaved natural fibers. The samples were constructed manually using Taguchi's orthogonal arrays, jute fibers, fly ash, and various chemical fiber exposure period amounts. Different machine-learning regression models are used to identify the relationship between input and output properties [22]. After being alkali-treated, Sajin et al. characterized the jute fiber optic composites' thermal, mechanical, and morphology properties. The analysis above urges a large impact on the polymer industries by utilizing the developed ecological composites in diverse lightest and greater hardness applications [23]. Jute composites showed lower impact results due to the higher interface adhesion. The higher interface adhesion between the matrix and the fibers produces a lack of energy absorption mechanism in the impact test. Jute composites showed good mechanical properties compared to other natural fibers because of the higher wettability of the fibers by the low initial viscosity thermoset resin [24]. Balcıoğlu et al. investigated the mechanical properties of SiC filler jute fiber composites and found that tensile behavior is superior to the impact test. Additionally, filler can be used to increase the lifetime of compression in jute fiber composites [25]. The 5 % NaOH-treated fiber-reinforced polyester composites have a 15.6 % increase in flexural strength compared to the 10 % NaOH-treated jute fiber-reinforced polyester composites. In contrast, it was 20 percentage for jute-epoxy composites. The jute-polyester composite seemed to have better impact energy than jute-epoxy composites [26]. It is found that 0° composite orientations are capable of absorbing sufficient impact energy for 5 ms^{-1} but not for velocity greater than 10 ms^{-1}. When fiber orientations were used between 15° – 45°, the composite impact resistance increased, indicating two significant peak forces [27].

2.3. Numerical simulation on composites

Alemi-Ardakani et al. used Abaqus/Explicit to simulate the 200 J collision of composites made of fiberglass and polypropylene. The fabric was progressively harmed when using the constructed failure criterion damage criterion. The preliminary simulation, built on the material characteristics from nonlinear static test cases, differed significantly from the outcomes of the destructive testing [28]. Jensen et al. evaluated a full-scale composite wind energy blade for fracture against tendon pressure. The development of local displacement measurement technology allowed for the recording of displacements throughout the loading history. Local displacement measurements were used to locate the point at which the catastrophic failure was initiated [29]. Torre et al. investigated the sandwich construction's ability to absorb energy when hit by a single impact and the creation of criteria that can be used to choose materials. Compared to conventional sandwich structures, corrugated sandwich panels have demonstrated superior strength and energy absorption capabilities [30]. Fish et al. described several techniques regarding matrix nutrients and foundation. The topic of selecting the right scale is covered and discussed with matrix nutrients among the various temporal applications [31].

2.4. Morphology of jute fiber

Jute grows significantly and has very important features, such as the external plants being "individually tailored" to produce fabric, and the interior stalk and external plants being divided. The parts are divided and washed to get rid of dust from the plant. The fiber is sent to jute mills for conversion into hessian and jute yarn after cleaning. Due to government organizations' assistance for R&D and also because of the jute, a variety of lifestyle items are manufactured from it and expanded into several forms [32]. Since jute fiber is entirely biodegradable, reusable, and green, it is a good choice for the environment. The term "Golden Fiber" refers to the natural fiber's golden and silky sheen. It guarantees that fabrics are better breathable and have a high yield strength and minimal flexibility. Because of this, jute is ideal for bulk packaging of agricultural products. Making the highest quality commercial yarn, fabric, net, and bags is made easier by this. It is among the most adaptable natural fibers utilized as raw materials for the packing, textile, nontextile, building, and agricultural industries. When yarn is bulked, the resulting ternary blend has a lower breaking tensile strength and a higher breaking elasticity [2].

Composites that were treated with NaOH, and supplemented with nano-clay had their dynamic mechanical and physical properties and vibration properties examined by Ramakrishnan et al. It is assumed that sodium hydroxide treatment (NaOH) enhances the mechanical characteristics by partially expelling hemicellulose and lignin and roughening the fiber surface, which produces an adhesion between the polymer and fiber that functions as an anchor. Another expectation is that the fiber and polymer will form a strong bond as a result of the hydroxyl group reaction with sodium hydroxide [21]. The mechanical characteristics of polymer hardness are the complete list of thermoplastics demonstrated by LDPE, followed by polylactide and PVC, while the higher impact strength is demonstrated by polypropylene. PVC, followed by poly (lactic acid) and Polyethylene, has the highest density of any thermoplastic material. Of the thermoset polymers addressed, resin does have the best strength properties, followed by thermoplastics and thermosetting polymers, while polyphenol has the ultimate tensile flexibility. Table 1 shows the mechanical properties of jute fiber [19].

2.5. Epoxy and binding element

Epoxy resins are the thermoset material most frequently utilized in polymer matrix composites. They are a class of thermoplastic plastic

Table 1
Mechanical properties of jute fiber.

Properties	Amount
Moisture content (%)	1.1
Tensile strength (MPa)	393–773
Pectin (%)	0.2
Diameter of fiber(μm)	5–25
Density (g/cm3)	1.46
Hemi-cellulose(%)	12
Elongation (%)	1.16–1.5
Micro-fibrillar angle (°)	8.0
Cellulose (%)	64.4
Young modulus (GPa)	13–26.5
Fiber length (mm)	0.8–6
Lignin (%)	11.8
Price (EUR/kg)	0.3
Waxes (%)	0.5

materials that do not emit reaction products during curing. As a result, they have low cure deformation, good adhesion, chemical and insulating capabilities, and enhanced biological and chemical resistance. Since the polymerization reaction is needed to create their results in varying chain lengths, epoxy resins are polymorphic or semi-polymeric compounds rarely found as pure substances. For some uses, highly pure grades can be produced. Purified liquid grades can form crystal solids due to their extremely regular structure, which necessitates melting to process them. A type of thermosetting resin known as epoxy resins is created through the hexagonal polymerization of substances with, on average, over one epoxy component per molecule.

2.6. Comparison of other composite material property

Jute, sisal, banana, and coir are the most common natural fibers produced around the world. These fibers are commonly utilized for various applications, such as cordage, sacks, fishnets, matting, and rope, as well as stuffing for mattresses and cushions. Cellulosic fibers can be obtained from several sections of plants. The economical, biodegradable jute goods combine with the soil after use, adding to the soil's accretion. Jute burns with no harmful fumes because it is formed of cellulose. Due to its low density and relatively stiff and robust behavior, jute fiber's unique characteristics can be compared to those of glass and some other fibers. As compared to other natural fibers, jute has a high tenacity and aspect ratio. Jute is a type of cellulosic fiber, and its composites have intermediate tensile and flexural strength with good impact strength. The world focuses on the inherent qualities of jute fiber, such as its low density, low elongation at break, and unique stiffness and strength comparable to those of glass fiber. Composites with the same system of reinforcing materials may not perform better since they are subjected to a variety of loading circumstances over the course of their service life. Hybrid composites are the greatest answer for these applications in order to address this issue. In a hybrid composite, one type of fiber balances the lack of another fiber by combining two or more different types of fiber. Hybridization aims to produce a new substance that will retain the positive attributes of its parts while excluding their negative ones. Based on the types of reinforcement, polymer composites can be divided into particle-reinforced polymer composites and fiber-reinforced polymer composites. Particulate composites, also known as particle-reinforced composites, include reinforcing material in the form of particles. There may be different reinforcing particles, such as spherical, platelet-shaped, cubic, tetragonal, or of other regular or irregular geometry. Table 2 shows the comparison of properties of different composite materials.

In most of the cases, tensile strength and flexural strength were measured to determine the mechanical properties of the fabricated composites. Some studies focused on impact strength also. So, tensile and flexural tests are the most critical tests to focus on for composites, as they offer comprehensive data on the composites' elasticity, durability, and resistance to deformation under various loading conditions.

3. Methodology

3.1. Study design

The step-by-step procedure for this study is shown in Fig. 2. It starts

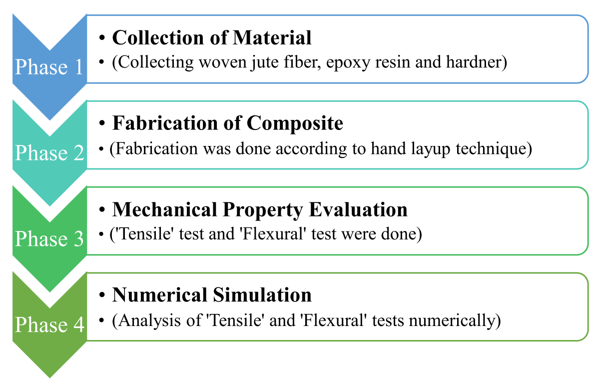


Fig. 2. Flow diagram of the working procedure.

Table 2
Comparison of properties of other composite materials.

Reinforced materials	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/m^2)	Applications	References
Basalt + jute	130	410	22	Roofing tiles, insulation panels	[33]
Glass + carbon	286.4	314.4	–	Marine industry, sports equipment	[34]
Kenaf + jute (K/J/K)	43.21	75.7	–	Packing material and material that absorbs oil and liquids	[35]
Carbon + basalt	354	400	–	Pipelines, beams, various car parts	[36]
Oil palm + kenaf	62	110	1.3	Building materials and animal feed	[37]
40 % Jute + resin	39.67	65.87	178.56	Textile, automobile	[1]
Coconut leaf sheath (CLS) + jute + glass	12.25	59.7	22.8	Roofing tiles, wall panels, furniture industry	[38]
Aramid + kenaf	202	15	34.8	Textile industries, insulation	[39]
Carbon + kevlar	388	2029.2	–	Defense industry, automotive industry	[40]
Carbon + flax	–	–	37	Printed banknotes and rolling paper for cigarettes	[41]
20 % Magnesium hydroxide + 40 % of kenaf	39	88	29	Building materials, packaging materials	[42]
Carbon fiber + 10 % carbon black	108.2	103.3	18.7	Automotive and aerospace industry	[43]
24 % kenaf + 16 % banana (plain woven)	140	170	–	Furniture, boxes	[44]
29 % Carbon + 14 % flax	222.63	–	–	Renewable energy	[45]

with the collection of materials and ends with the analysis of the result. Mechanical and numerical analyses were done for both tensile and flexural/bending tests.

3.2. Collection of material

3.2.1. Woven jute fiber

Woven Jute Fiber was obtained from the nearby jute mills. The woven jute fiber was acquired from nearby jute mils in Khulna, Bangladesh, with an overall body mass of 1.3 g /cm^2 and a depth of 3 mm. Jute fibers have significant benefits, including minimal cost, environmental friendliness, and reasonable physical qualities. Fig. 3 depicts a sample of woven jute fiber.

3.2.2. Epoxy resin and hardener

Epoxy resin and hardener were used in this fabrication. The resin-hardener mixture had a 3:1 ratio. Epoxy resin is a type of resin with excellent mechanical qualities, excellent resistance to chemicals, and high adhesion strength, making it extremely useful. It has numerous applications in technological and industrial areas. Curing occurs at huminitic conditions with the use of hardener. In the current study, epoxy obtained from a local chemical plant is used.

3.3. Fabrication of composite

Significantly, many different techniques and methods are used to create composites. The manual mixture of fabrication is one of the most straightforward ways to make composites. The manual mixture process was used to create all the composite layers. As reinforcement, five layers of jute fiber and epoxy are utilized as the matrix substance. Jute of 52.5 % and 47.5 % of resin and harder combination are used for making composite materials. Three respects to one epoxy are used to create the matrix. To strengthen matrix adhesive properties and provide strength to the composites, Epoxy resin was utilized as the matrix, along with hardener. The fabrication procedures performed are shown in Fig. 4.

3.3.1. Step-by-step procedure of fabrication

The fabrication procedures were performed sequentially as below:

- Step 1: The experimental bench was covered with wrapping paper to create a smooth surface for construction. All fibers cut according to the design were laid on the bench.
- Step 2: The fibers were cleaned and sun-dried. A 3:1 mixture of resin and hardener was combined in a ceramic dish. A spinner was used to dilute the epoxy and hardener until the hardener was entirely combined with the epoxy. An open mold was designed for the fabrication procedure.
- Step 3: Next, a matrix layer is applied to the fabrication area inside the mold cavity. A roller, such as a pen, was employed to ensure layer consistency.
- Step 4: Jute fiber is laid on the matrix layer, and a die is used to provide pressure to fix the matrix layer correctly.
- Step 5: Again, the matrix layer is deposited on the jute mat using a roller, and the jute mat is placed on top of the matrix layer. This method was repeated, and five layers of jute fiber were used. A combination of 52.5 % jute and 47.5 % epoxy resin and harder was used.
- Step 6: The sample was then wrapped in plastic wrappers and crushed with a couple of blocks.
- Step 7: To obtain excellent composite strength, a cure period of at minimum 70–72 hours was specified. The molds were shattered, and the components were withdrawn after they had thoroughly cured. The fabrication apparatus was completely dismantled.
- Step 8: All specimens were scaled to the desired dimension for various mechanical tests.
- Step 9: Finally, specimens were cut using grinding equipment from a nearby machine shop and were ready for tensile and flexural/ bending tests.

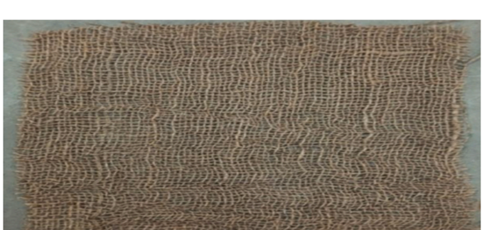


Fig. 3. Woven jute fiber.

3.4. Mechanical property evaluation

Mechanical characterization, tensile and flexural test were performed following fabrication. As per the literature review the impacat test shows less significance than tensile and flexural, the study focused on identifying optimum fiber composition in evaluating best mechanical property.This was accomplished through the use of a tensile and flexural test. Many researchers based their study on the results of these experiments.

3.4.1. Tensile test

Composite materials are tested in several ways, such as the tensile test. This test is used to evaluate elastic and plastic deformation. It determines the needed force as well as the elongation point at break. Nowadays, the uniaxial test is widely performed. Several characteristics were required to examine the specimen. Again, tensile testing is a basic form of resting process used by scientists and researchers. This test is necessary for examiners for new product development, design, manufacture, and prototype testing. This approach is used to measure stress and strain parameters. This is also used to generate a stress-strain curve. It is essential throughout study and innovation to determine acceptable materials. It may also be performed to ensure that substances meet the required hardness and elasticity specifications. Table 3 shows the tensile test result.

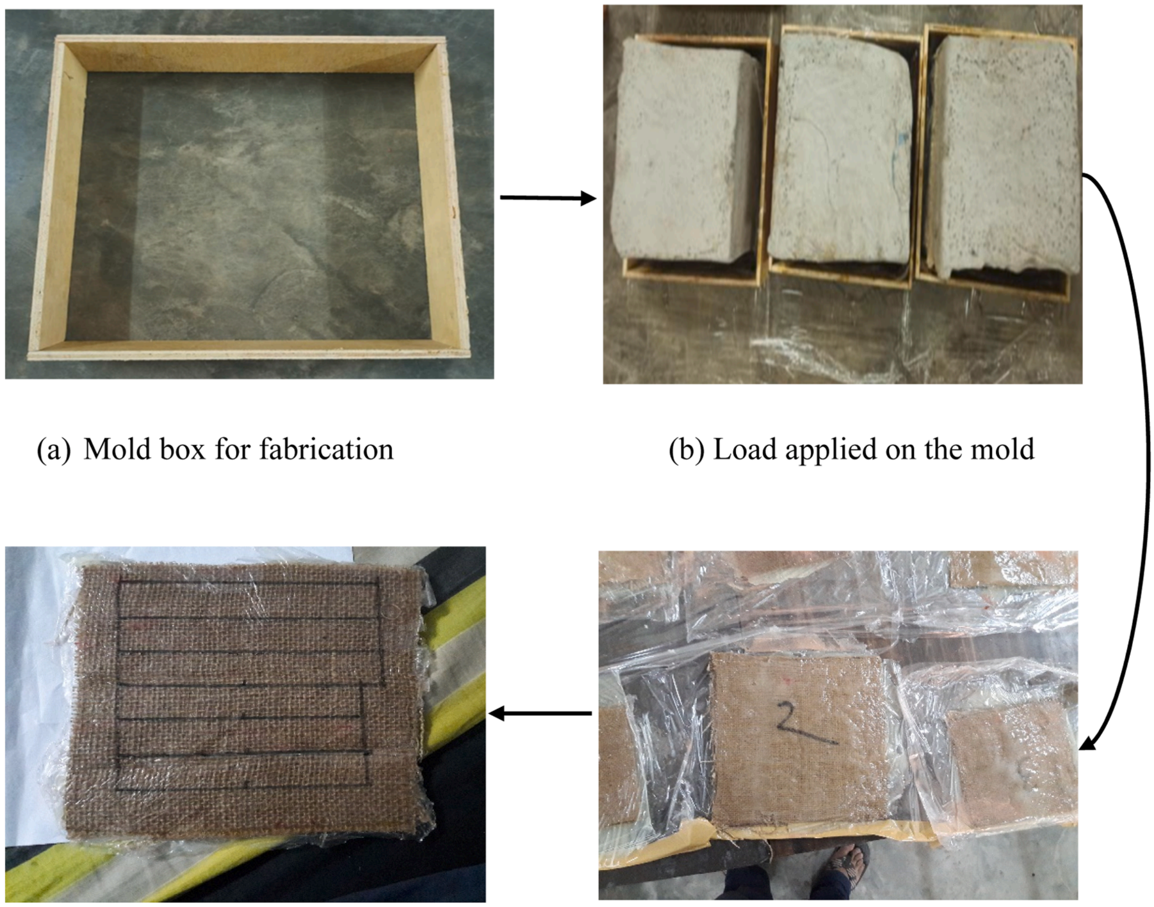
ASTM D3039 was used as the standard for specimen size. To begin, a grinding machine was used to cut the specimen into standard size. Then, it was set into the universal testing machine's jaws. The lower half of the specimen was then fixed, and the upper part of the specimen was loaded. Determine the force required and the elongation point of break.

3.4.2. Flexural test

Flexure experiments are commonly used to assess a product's bending stress or fracture toughness. Deflection examinations are less cost-prohibitive than other testing; however, the results can differ slightly. A sample is placed parallel to the ground above two different interaction locations (minimum operating frame). Then, stress is transmitted to the material's top via one or more locations of interaction (axial load frame) till the sample fails. Also, the sample's strength and stiffness are represented by the measured maximum force.

In this experiment, the three-point bend test is used. The specimen was placed horizontally at the top two points, and the force was delivered to the sample's upper surface through a single point such that the sample was curved in the shape of a "V." The three-point flexure test is excellent for assessing a single sample location. ASTM D7264 was used for sample dimensions 120 mm × 20 mm × 5 mm and cut by using a grinding machine. Fig. 5 represents the specimen for the bending test.

The wheel was then used to progressively apply load to the center of the specimen. The sample is broken, i.e., fractured, at a particular load. The displacement was measured using a scale placed in the center of the specimen. The corresponding load is noted for the gradually rising distortion of the specimen, and then calculation is required to determine bend stress.



(a) Mold box for fabrication (b) Load applied on the mold

(d) Sample standard size (c) Unload the mold

Fig. 4. Fabrication of jute fiber composite.

Table 3
Tensile test result.

Load (kN)	Displacement (mm)	Stress (MPa)
0.310	0.026	7.48
0.635	0.052	15.21
0.900	0.074	21.64
1.095	0.080	26.32
1.310	0.101	31.47
1.490	0.123	35.77
1.650	0.136	39.67
1.785	0.147	42.91

Fig. 5. Specimen for bending test.

4. Results and discussions

4.1. Experimental investigation of tensile test

Tensile Strength, S_t = F / A
Here, F = Force

A = Cross Sectional Area
= Width × Thickness
= $b \times h$

Tensile test results for different specimens are shown in Table 3. The displacement versus stress curve is given in Fig. 6.

As shown in Fig. 6, the stress rises as the displacement value rises. As a result, a high displacement rate implies higher tensile strength. The standard value is compared to the research work of a journal paper that is cited. Table 4 shows the tensile strength for different jute weights [1].

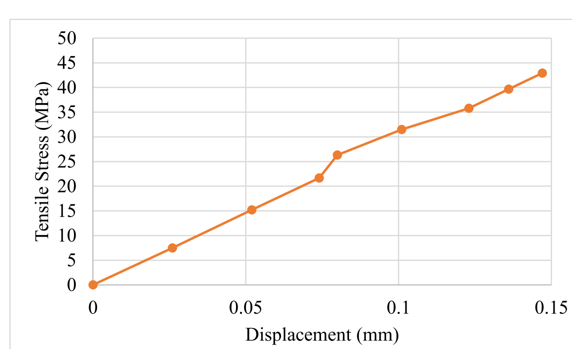


Fig. 6. Displacement versus tensile strength curve.

Table 4
Reference tensile strength of jute fiber.

Jute weight (%)	Tensile strength (MPa)
40	39.67
30	35.77

4.2. *Experimental investigation of flexural test*

Bending Strength, σ = MC / I
Here, *M* = Internal bending moment about the sections of the neutral axis
= Force × Distance
= *P* × *a*
C = Perpendicular distance from the neutral axis to the furthest point on the section
= thickness / 2
= *h* / 2
I = Moment of Inertia
= 1/12 × width × $(\text{thickness})^3$
= 1/12 bh^3

Bending test results for different specimens are shown in Table 5. The displacement versus flexural strength curve is given in Fig. 7.

As shown in Fig. 7, the flexural stress increases as the displacement value increases. As a result, a high displacement rate indicates greater flexural strength. The standard value is compared to the research work of a cited journal paper. Table 6 shows the flexural strength of different jute weights [1].

5. Numerical analysis

5.1. *Tensile test*

5.1.1. *Numerical model*

Fig. 8 shows the dimensions of the numerical model. The geometry and material information listed below are needed to model this scenario. Used standard is ASTM D3039 [46–49].

Layer of the Specimen:
Thickness: total 5 mm, each layer 0.5 mm
Layer 1,3,5,7,9 = Jute fiber
Layer 2,4,6,8,10 = Epoxy Resin

5.1.2. *Defining the geometry*

The main geometric model is created by using ABAQUS Workbench. The geometry created by using Abaqus is displayed in Fig. 9.

5.1.3. *Material properties*

The mechanical behavior of the finite element model's parts is defined by material models. Young modulus of 26,500 MPa and Poisson's ratio of 0.4 were selected as the specimen mechanical properties of jute fiber. Abaqus was used to modify the properties. Table 7 shows the properties of jute fiber and epoxy resin [1].

Table 5
Bending test result.

Load (kN)	Displacement (mm)	Stress (MPa)
0.015	0.112	8.13
0.025	0.197	14.27
0.045	0.394	28.54
0.06	0.549	41.27
0.08	0.709	51.32
0.085	0.776	56.18
0.95	0.864	62.53
0.105	0.957	69.3

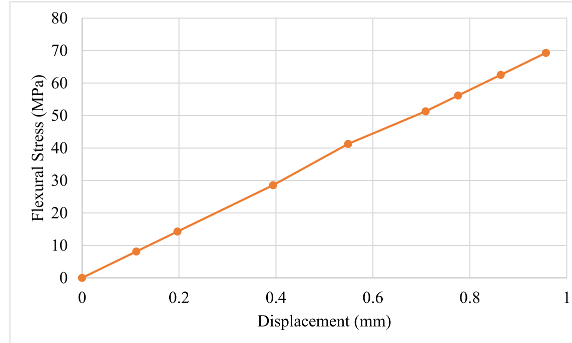


Fig. 7. Displacement versus flexural strength curve.

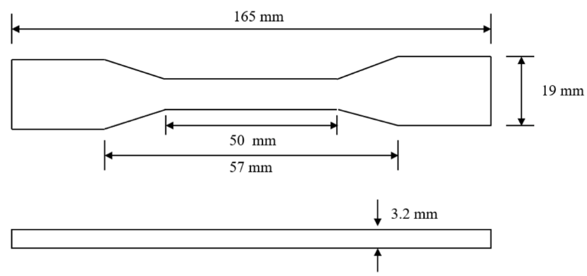


Fig. 8. Dimension for the numerical model.

Table 6
Reference flexural strength of jute fiber.

Jute weight (%)	Flexural strength (MPa)
40	65.87
30	62.87

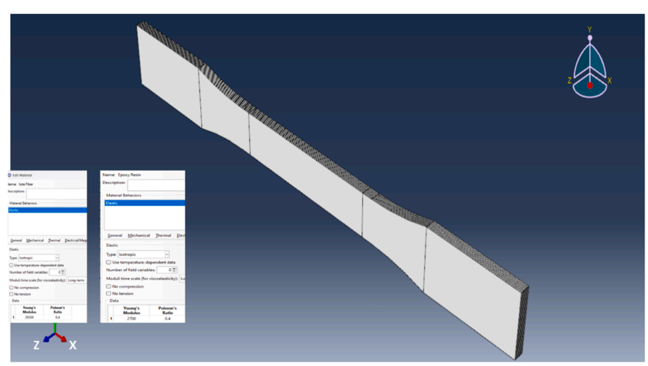


Fig. 9. Specimen geometry for tensile test.

Table 7
Properties of jute fiber and epoxy resin.

Properties	Young modulus (GPa)	Poisson's ratio	Density (g/ cm^3)	Specific Gravity (gm/cc)
Jute Fiber	26.5	0.4	1.3	1.3
Epoxy Resin	2.7	0.4	1.2	1.8

5.1.4. *Meshing*

The follow-up interviews stage helps to divide the uninterrupted rigid face geometry, also known as meshing. Here, the general mesh is employed. In total, there are 8040 elements and 9996 nodes. The model for numerical analysis meshing is displayed in Fig. 10.

5.1.5. Boundary conditions

First, one fixed support is placed on one end of the specimen in the other half to provide force to the geometry. This aids in limiting the degrees of freedom between any ends.

The upper part of the board is then subjected to a force in the Positive x direction. Here, the force was applied to one side of the body. The right face and force are applied on the geometry, with the right magnitude and direction [46] [49]. The boundary conditions are shown in Figs. 11 and 12.

5.1.6. Total deformation

The contour graphic represents the overall deformation in Fig. 13. Upon first inspection, the anticipated displacements appeared to be perfect. The experimental findings indicate a maximum deformation of around 0.147 mm.

Also, the simulated specimen was thought to be a homogenous material; the greatest deformation in this FEM result is 0.147 mm, which stress differs slightly from the experimental value.

The numerical results of the tensile test are shown in Table 8. Fig. 14 shows the displacement versus tensile stress curve.

Fig. 15 shows the numerical simulation data of fabricated composite laminates. For this the material property had not enough plasticity, therefore the curve was straight. The substance was broken down at its peak.

5.1.7. Comparison between numerical and experimental results

A comparison of experimental and numerical results is shown in Fig. 16. The deviation of the numerical and experimental analysis is acceptable. In both analyses, the displacement value for stress is relatively similar. As a result, we can conclude that the experiment and numerical results are identical.

5.2. Bending test

5.2.1. Numerical model

The geometry shown in Fig. 17 is needed to model this scenario. Used standard is ASTM D7264 [47,50–52].

5.2.2. Defining the geometry

The main geometric model is created by using ABAQUS Workbench. The geometry created by using Abaqus is displayed in Fig. 18.

5.2.3. Material properties

The numerical simulation model's parts' mechanical behavior is defined by material models. Jute fiber's Young Modulus of 26,500 MPa and Poisson ratio of 0.4 was chosen as the specimen's mechanical characteristics. Utilizing Abaqus, the attributes were altered.

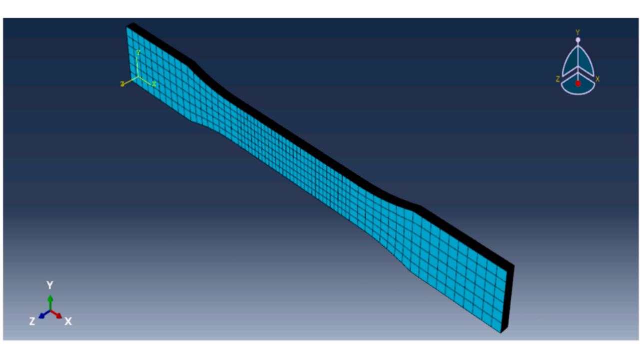


Fig. 10. Meshed specimen for tensile test.

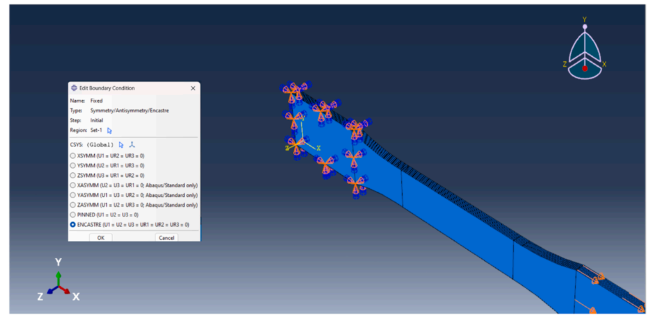


Fig. 11. Fixed support of the specimen for tensile test.

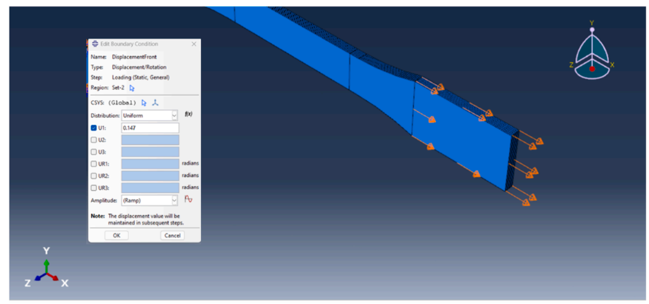


Fig. 12. Forced applied one side of the body for tensile test.

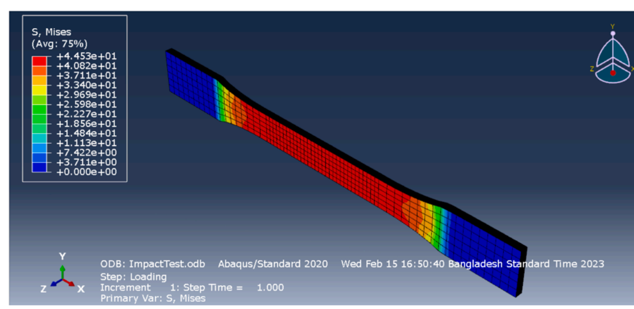


Fig. 13. Contour plot of total displacements for tensile test.

Table 8
Numerical results of tensile test.

Displacement (mm)	Stress (MPa)
0.026	9.16
0.052	16.83
0.074	23.57
0.080	27.94
0.101	33.42
0.123	38.02
0.136	41.67
0.147	44.53

5.2.4. Meshing

The follow-up interviews stage helps to divide the uninterrupted rigid face geometry, also known as meshing. Here, the general mesh is employed. In total, there are 9398 elements and 10,818 nodes. The model for numerical analysis meshing is displayed in Fig. 19.

5.2.5. Boundary conditions

To give the geometric force, two connecting pillars are first put on the two corners of the platform in the lower half. As a result, the boundary conditions between any two corners are restricted. The result

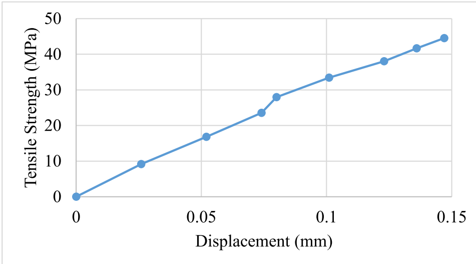


Fig. 14. Displacement versus tensile stress curve.

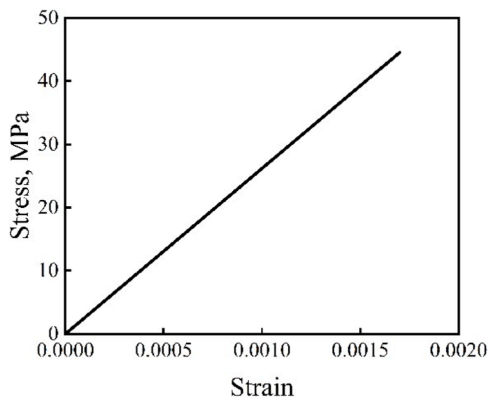


Fig. 15. Numerical stress-strain curve of tensile test.

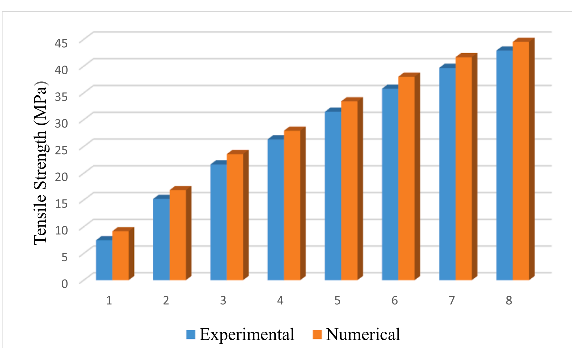


Fig. 16. Comparison of numerical and experimental results.

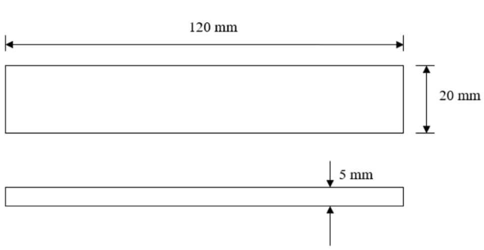


Fig. 17. Numerical model for bending test.

is comparable to Fig. 20. The loading nose was applied in the negative y direction shown in Fig. 21.

The upper part of the board is then subjected to a force in the negative z direction. Here, the force was applied using the 1 mm of the central part of the body. On the geometry, the right face and force are applied, with the right magnitude and direction [50,53,54].

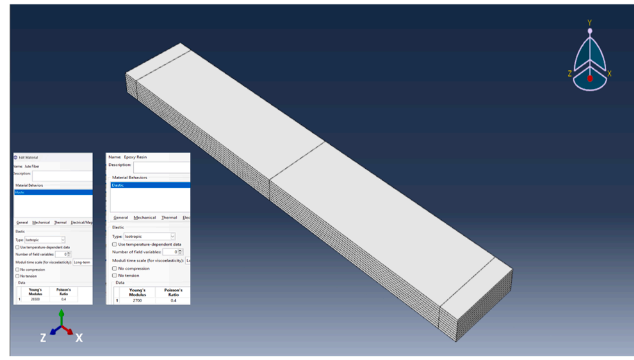


Fig. 18. Specimen geometry for bending test.

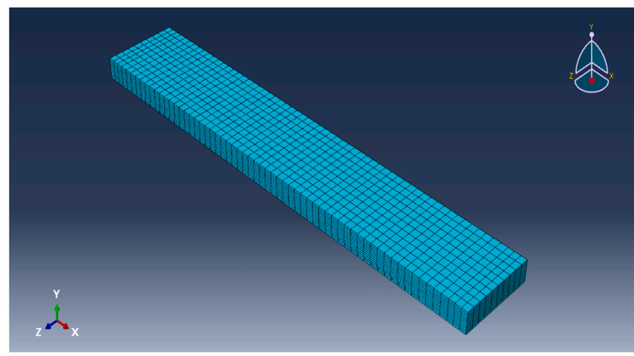


Fig. 19. Meshed specimen for bending test.

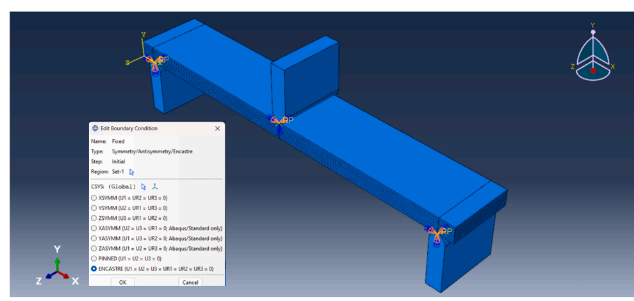


Fig. 20. Fixed support of the specimen for bending test.

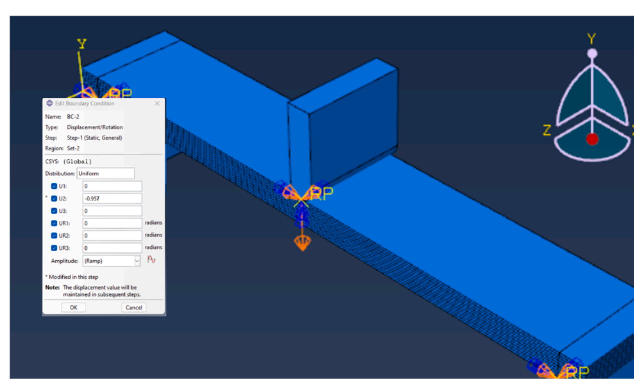


Fig. 21. Forced applied on the middle portion of the body for bending test.

5.2.6. Total deformation

A contour graphic representing overall deformation is shown in Fig. 22.

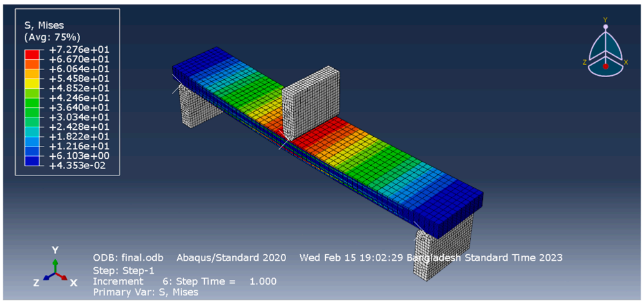


Fig. 22. Contour plot of total displacements for bending test.

On first inspection, the anticipated displacements appear to be perfect. The experimental findings indicate a maximum deformation of around 0.957 mm. Also, the simulated specimen was thought to be a homogenous material; the greatest deformation in this FEM result is 0.957 mm, which stress differs slightly from the experimental value.

Here, the numerical result of bending test is shown in Table 9. Fig. 23 shows the displacement versus bending stress curve.

Fig. 24 is a graph of numerical simulation data, and the stress-strain curve is generated using this data. For this the material property had not enough plasticity, therefore the curve was straight. This material behavior is similar to jute-glass reinforced epoxy composites [55]. The substance was broken down at its peak.

5.2.7. *Comparison between the numerical and experimental results*

Here is a comparison of experimental and numerical results. There is a very slight variation here. In both analyses, the displacement value with respect to stress is relatively similar. As a result, we can conclude that the experiment and numerical results are identical. Fig. 25 shows the comparison of numerical and experimental results.

Measurement entails acquiring quantitative data regarding a single property of a subject. In contrast, evaluation incorporates the larger context of using a well-defined evaluation condition (EC) to assess the subject's overall performance. For relevant subject comparisons and analyses, a well-defined EC is necessary [56]. We establish equivalent evaluation conditions (EECs) by ensuring that the same mechanical tests (e.g., tensile strength test, flexural strength test) are applied uniformly across all composite samples. This approach guarantees that the evaluation outcomes are comparable. Authentic and consistent evaluation results are achieved through the rigorous application of EECs.

In previous research work, Rafiquzzaman et al. [1] used 40 % jute and 60 % epoxy resin and harder. Their flexural strength and tensile stress were measured at 65.87 MPa and 39.47 MPa, respectively. The high level of epoxy resin content in their fabricated composite resulted in several limitations, leading to increased costs. When we found significant limitations to using a combination of jute fiber and other materials, we designed and fabricated 52.5 % jute and 47.5 % epoxy material. For the optimization of the layer design, we combined five layers of jute fiber and epoxy resin, the design of which also increases the value of mechanical properties. In our optimistic design and fabrication, we finally found that the mechanical properties of flexural stress

Table 9
Numerical results of bending test.

Displacement (mm)	Stress (MPa)
0.112	12.02
0.197	17.78
0.394	32.16
0.549	43.32
0.709	54.71
0.776	59.64
0.864	65.85
0.957	72.76

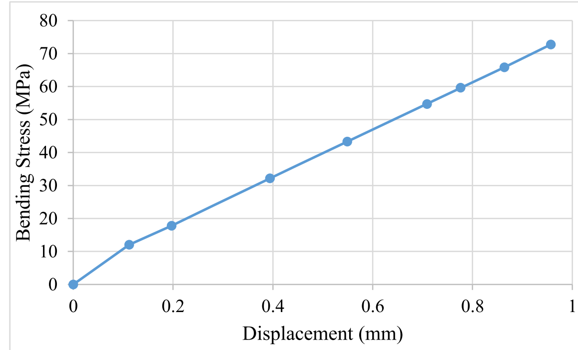


Fig. 23. Displacement versus bending stress curve.

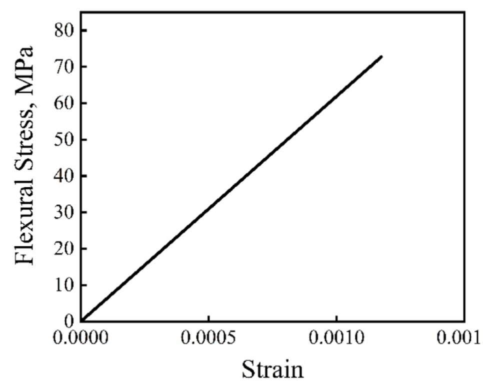


Fig. 24. Numerical stress-strain curve for flexural test.

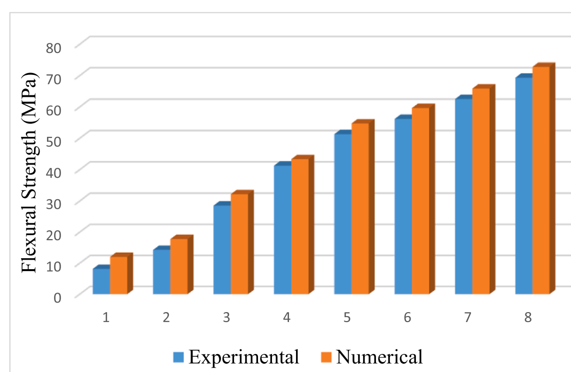


Fig. 25. Comparison of numerical and experimental results.

and tensile stress are 69.30 MPa and 42.91 MPa. So, our design and manufacturing boosted flexural strength by 5.2 % and tensile strength by 8.7 %. We observed that there were significant limitations in using the percentage of jute fiber and resin. Epoxy resin is more expensive than natural fibers like jute. Our design uses a higher percentage of jute, which will impact the cost. This jute is available both in Bangladesh and worldwide. Our composite materials increase the percentage of jute materials, which will reduce the cost of various applications. Jute fiber absorbs moisture levels that are high in the environment. We design and fabricate our composite in an optimized way. That is why resin can protect from swelling, degradation, or microbial growth. Jute fiber is bio-friendly and biodegradable, which contributes to environmental sustainability. We optimize the proportion of jute fibers in the composite. We prefer sustainable materials over petroleum-based products like epoxy resin. This optimized design and fabrication material aligns with global trends toward greater environmental friendliness. Jute reduces the use of alternative synthetic materials like nylon, glass, and polyester. This will reduce plastic waste and carbon emissions linked to the SDG goal. A lighter, customized, and optimized design also contributes to energy efficiency, specifically in transportation applications, by reducing fuel consumption and emissions. Our composite design and fabrication effectively balance mechanical performance, cost-efficiency, and environmental sustainability.

6. Conclusions and recommendations

Throughout the work, composites made from jute fiber were constructed, and their mechanical capabilities were assessed. The study's findings are as follows: Epoxy effectively fabricates new bio-composites reinforced with jute fiber. The current experiment's findings demonstrated that composites reinforced with jute and epoxy resin can achieve the required levels of tensile strength (42.91 MPa) and bending strength (69.30 MPa). The numerical results differ somewhat from the experimental results. It is a result of the specimen being treated as a homogeneous material throughout numerical analysis. However, numerical analysis of various natural fibers with different compositions can also be used without creating a physical shape. This would undoubtedly aid in lowering the significant quantity of manufacturing costs. Finally, our composite design, fabrication, and optimization have the potential to improve mechanical properties, decrease composite weight, reduce resin cost, and increase material sustainability. The proposed design and composition will be adapted to obtain lightweight features in various applications, including components for automobiles, door handle sheets, bicycle seat backs, and baggage covers. For some light load-bearing tasks, the bending strength of jute fiber-based biodegradable polymers can be beneficial. Based on the precise hardness that this compound will deliver, designers can use the results of this research to create products using jute fiber-based polymer composites. The most important finding of this study is that jute, which is regarded as an environmental contaminant, may be used to create goods that could replace expensive glass fiber-based composites and contribute to the development of healthier ecosystems for humans and the environment.

Different organic materials may be applied to increase mechanical features. Future scholars will have much freedom to conduct additional research in this field. Optimization and cost function analysis may also be added in the future. Impact tests can also be done for further study using filler materials, as tensile and flexural tests play a more vital role, as observed in the discussion and literature review. The orientation angle will also be an important element for this type of investigation, and it can be modified. The composites can be used in interior furniture, automobile parts, building materials, and marine transportation sectors. Hence with this conclusion, it is sure that the technology shows composite is the most wanted material in the recent trend.

CRediT authorship contribution statement

Tarikur Jaman Pramanik: Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft. **Md. Rafiquzzaman:** Conceptualization, Formal analysis, Investigation, Methodology, Software, Supervision, Writing – review & editing. **Anup Karmakar:** Writing – review & editing. **Marzan Hasan Nayeem:** Writing – review & editing. **S M Kalbin Salim Turjo:** Writing – review & editing. **Md. Ragib Abid:** Writing – review & editing.

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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