

# MECHANICAL CHARACTERIZATION OF WATER HYACINTH FIBER REINFORCED EPOXY COMPOSITES UNDER TENSILE AND FLEXURAL LOADING

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**ABSTRACT:** Mechanical Characterization of Water Hyacinth Fiber Reinforce Epoxy Composite Under Tensile and Flexural loading using water hyacinth (*Eichhornia crassipes*) as reinforcement and epoxy resin as the matrix material. The composite was fabricated using the hand lay-up technique, which is a simple and cost-effective method suitable for laboratory-scale production. The fiber extraction process involved collection, cleaning, drying, and manual separation to obtain usable fibers.

A fiber-to-matrix ratio of 30:70 (by weight) was selected to achieve a balance between strength and workability. The epoxy resin and hardener were mixed in a 2:1 ratio to ensure proper curing and bonding. The fabricated composite specimens were prepared according to ASTM standards (D3039 for tensile testing and D790 for flexural testing) to ensure reliable and standardized results.

Mechanical testing was carried out at IIT Kanpur to evaluate tensile and flexural properties. The tensile test results of Sample 1 exhibited higher tensile strength (6.91 MPa), greater strain, and better energy absorption compared to Sample 2 (3.48 MPa), indicating superior ductile behavior. The stress–strain curves also showed zig-zag patterns due to non-uniform fiber distribution, porosity, and micro-crack formation.

In Flexural Test, the flexural strength for both the specimen is 28MPa indicate the uniformity in fabrication and consistency in material composition. However flexural modulus indicate stiffer and resist. Sample 1 demonstrates higher strain at failure indication better ductility.

The results demonstrate that water hyacinth fiber can be effectively utilized as a reinforcement material in polymer composites. This study highlights the potential of converting an invasive aquatic plant into a value-added engineering material, contributing to sustainability and environmental management.

Keywords:- Mechanical Characterization, Water Hyacinth Fiber, flexural

**1.1 INTRODUCTION:** One day, while watching a video on YouTube, I came across an inspiring story about **Mr. Gaurav Anand**, who joined the Namami Gange Mission under the Swachh Bharat Mission with the aim of cleaning the River Ganga. What attracted me the most was that he had left his 16-year corporate job to work for environmental sustainability and social welfare. His innovative work on converting water hyacinth into useful products, especially a unique saree made from water hyacinth fiber, deeply impressed me. This idea immediately caught my attention and inspired me to think differently about this aquatic plant.

During our childhood, many of us used to play with water hyacinth (*Eichhornia crassipes*) in ponds and small water bodies, often making toy boats from it for fun. At that time, it never occurred to us that this seemingly harmless floating plant is actually one of the most problematic aquatic weeds in the world. As I grew older and started understanding environmental issues, I realized that water hyacinth is not just a common floating plant but a major source of pollution and ecological imbalance in rivers, ponds, and lakes.

Water hyacinth is a fast-growing floating aquatic plant that spreads rapidly over the surface of water bodies. Its uncontrolled growth forms a dense mat on the water surface, which blocks sunlight from reaching the lower layers of water. Due to this, submerged aquatic plants are unable to perform photosynthesis properly. As a result, the oxygen level in water decreases significantly. This reduced dissolved oxygen level creates a harmful environment for aquatic animals, especially fish and other organisms, often leading to their death.

Moreover, the thick growth of water hyacinth obstructs the natural flow of rivers and canals. In stagnant water bodies, the plant multiplies rapidly and covers the entire surface, making the water body almost unusable. When these plants die, they decompose and produce a large amount of organic waste, which further deteriorates water quality. This decomposition process also creates an unpleasant foul smell, affecting the surrounding environment and public health. Therefore, water hyacinth not only pollutes water resources but also disturbs the entire aquatic ecosystem.

These thoughts remained in my mind from childhood, and when the time came to select a research topic, I started thinking seriously about this plant. Instead of considering it only as a waste material or an environmental problem, I began to ask myself an important question: Can this harmful aquatic weed be converted into something useful?

This curiosity motivated me to study water hyacinth in detail and explore possible methods to utilize it effectively. While researching, I found that water hyacinth contains a considerable amount of natural cellulose fibers, which can be extracted and used as a reinforcement material. This led me to think about its potential use in the field of composite materials and engineering applications.

The idea of transforming an environmental pollutant into a useful engineering material fascinated me. I started exploring whether water hyacinth fibers could be used to manufacture lightweight composite materials suitable for industrial parts and structural applications. In modern engineering, lightweight materials are highly desirable because they reduce the overall weight of components, improve fuel efficiency in transportation systems, and lower manufacturing costs.

At the same time, I also considered the social impact of this research. In many rural and economically weaker areas, water hyacinth is abundantly available in rivers, ponds, and wetlands. If this waste plant can be converted into valuable products or engineering materials, it can create employment opportunities for poor and unemployed people, especially in villages located near water bodies. People can be involved in the collection, drying, fiber extraction, and processing of water hyacinth, thereby generating a source of income. Thus, this research topic is not only important from an engineering perspective but also from an environmental and socio-economic point of view. It offers a sustainable solution to reduce water pollution, improve river cleanliness, and create livelihood opportunities.

Inspired by these thoughts and motivated by my childhood memories, I decided to work on the development of a composite material using water hyacinth as the key reinforcement material. The objective of this research is to investigate whether water hyacinth-based composites can serve as lightweight, eco-friendly, and cost-effective materials for engineering applications.

This work aims to contribute toward solving the problem of water hyacinth infestation while simultaneously promoting the concept of waste-to-wealth. By converting an unwanted aquatic weed into a useful composite material, this study supports the goals of environmental sustainability, river cleanliness, and green engineering. What started as a childhood memory and an inspiring YouTube video?

Eventually transformed into a meaningful research idea. This journey encouraged me to look at a common environmental problem from a scientific and innovative perspective. My research on water hyacinth composite material is therefore a small step toward creating a cleaner environment and a better future through sustainable material development.

## 2.1 TENSILE TEST

The tensile test was conducted as per ASTM D3039 using a Universal Testing Machine (UTM). The tensile properties of the composite were evaluated in terms of ultimate tensile strength and stress-strain behavior.

### 2.1.1 Experimental Observations

Two samples were tested under identical conditions. The dimensions of the specimen were:

- Width (b) = 14.2 mm and 15.1mm
- Thickness (d) = 10.6 mm
- Cross-sectional Area = 150.52 mm<sup>2</sup> and 160.06 mm<sup>2</sup>

**Sample 1 Results:**

- Tensile Strength = 6.91 MPa
- Strain at Break = 0.731 %
- Displacement at Break = 2.395 mm
- Maximum Load = 1.041 kN
- Young's Modulus = 1.19 GPa
- Energy Absorption = 0.21 J

Results Table 1													
	Force at Break (Standard) (kN)	Tensile strain (Strain 1) at Break (Standard) (%)	Tensile stress at Break (Standard) (MPa)	Displacement at Break (Standard) (mm)	Maximum Force (kN)	Tensile strain (Strain 1) at Maximum Force (%)	Tensile stress at Maximum Force (MPa)	Displacement at Maximum Force (mm)	Energy at Maximum Force (J)	Force at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Modulus (Automatic Young's) (GPa)	Elongation after fracture (%)
1	1.041	0.731	6.91	2.395	1.041	0.73	6.91	2.395	0.21	0.9	5.99	1.19	-----
Specimen Detail 1													
	User	Start date	Specimen number (included)	Specimen label	Geometry	Length (mm)	Width (mm)	Thickness (mm)	Area (mm <sup>2</sup> )	Rate 1 (mm/min)	Strain offset at Slack correction (Automatic) (%)	Corrected gauge length at Slack correction (Automatic) (mm)	Extension offset at Slack correction (Automatic) (mm)
1	ACMS	30-04-2026	1	1	Rectangular	50	14.2	10.6	150.52	2	0	50	0

**Table 2.1.1 a****Sample 2 Results:**

- Tensile Strength = 3.48 MPa
- Strain at Break = 0.349 %
- Displacement at Break = 1.481 mm
- Maximum Load = 0.557 kN
- Young's Modulus = 1.18 GPa
- Energy Absorption = 0.05 J

Results Table 2													
	Force at Break (Standard) (kN)	Tensile strain (Strain 1) at Break (Standard) (%)	Tensile stress at Break (Standard) (MPa)	Displacement at Break (Standard) (mm)	Maximum Force (kN)	Tensile strain (Strain 1) at Maximum Force (%)	Tensile stress at Maximum Force (MPa)	Displacement at Maximum Force (mm)	Energy at Maximum Force (J)	Force at Yield (Offset 0.2%) (kN)	Tensile stress at Yield (Offset 0.2%) (MPa)	Modulus (Automatic Young's) (GPa)	Elongation after fracture (%)
1	0.557	0.349	3.48	1.481	0.56	0.33	3.5	1.394	0.05	----	----	1.18	----
Specimen Detail 2													
	User	Start date	Specimen number (included)	Specimen label	Geometry	Length (mm)	Width (mm)	Thickness (mm)	Area (mm <sup>2</sup> )	Rate 1 (mm/min)	Strain offset at Slack correction (Automatic) (%)	Corrected gauge length at Slack correction (Automatic) (mm)	Extension offset at Slack correction (Automatic) (mm)
1	ACMS	30-04-2026	1	2	Rectangular	50	15.1	10.6	160.06	2	-0.01	50	0

Table 2.1.1. b

## 2.1.2 Stress–Strain Behavior

### Sample 1:

The stress–strain curve of Sample 1 shows a relatively smooth trend with minor fluctuations. The material exhibits:

- Initial linear elastic region
- Clear yield behavior
- Gradual plastic deformation before fracture

This indicates **ductile behavior**, where the material absorbs energy before failure.

Fig.2.1.2 a Tensile Testing Specimen 1



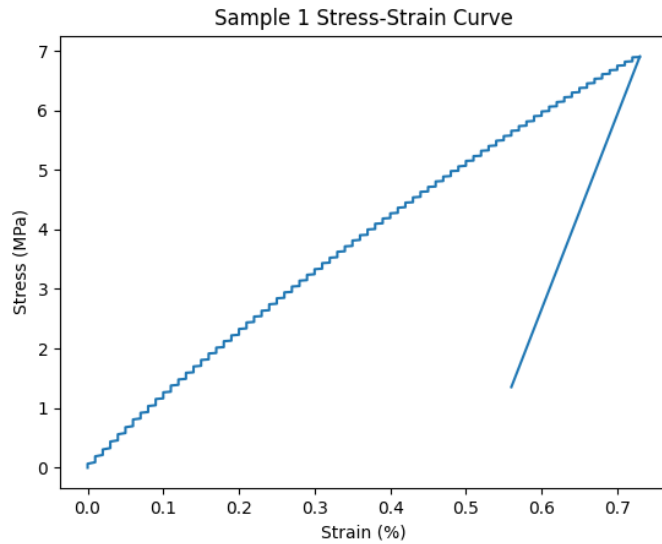


Fig2.1.2 b Sample 1 stress Strain Curve

**Sample 2:**

The stress–strain curve of Sample 2 shows:

- Abrupt failure
- No clear yield point
- Lower strain values

This behavior indicates a **brittle nature**, where the material fails suddenly without significant deformation.



Fig. 2.1.2 c Tensile Testing Specimen 2

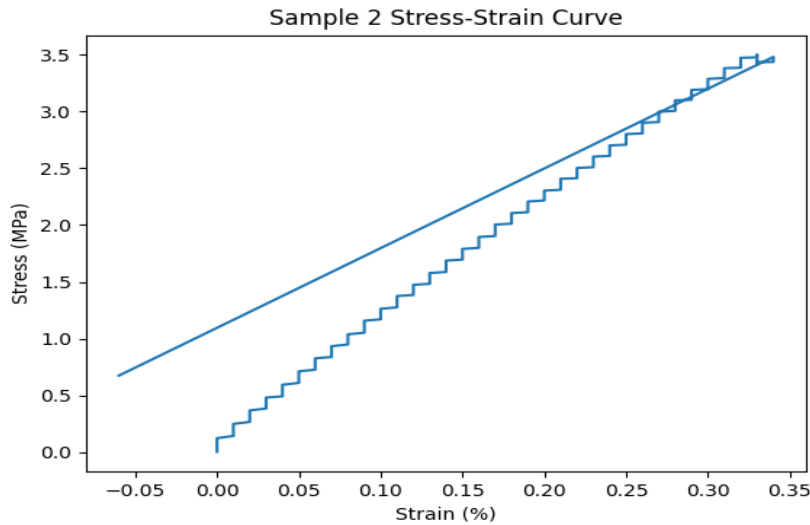


Fig. 2.1.2.d Sample 1 stress Strain Curve

### 2.1.3 Zig-Zag Behavior Analysis

The stress–strain curves show slight zig-zag patterns. This is attributed to:

- Non-uniform fiber distribution
- Presence of voids and porosity
- Weak interfacial bonding between fiber and matrix
- Micro-crack initiation and propagation

Such behavior is common in natural fiber composites and does not necessarily indicate experimental error.

### 2.1.4 Comparative Analysis

Property	Sample 1	Sample 2	Interpretation
Tensile Strength	6.91 MPa	3.48 MPa	Sample 1 stronger
Strain	Higher	Lower	Sample 1 more ductile
Energy Absorption	High	Low	Sample 1 tougher
Yield Behavior	Present	Absent	Sample 1 stable

Table 2.1.4

### 2.1.5 Discussion

The superior performance of Sample 1 can be attributed to:

- Better fiber-matrix bonding
- Lower porosity
- Improved stress transfer mechanism

In contrast, Sample 2 exhibits poor mechanical performance due to:

- Higher void content
- Weak bonding
- Non-uniform fiber alignment

The nearly equal Young's modulus in both samples indicates similar stiffness; however, the difference in strength and strain highlights the importance of internal structure and bonding quality.

### 2.1.6 Failure Mechanism

The failure modes observed are:

- **Sample 1:** Gradual fracture with fiber pull-out → ductile failure
- **Sample 2:** Sudden break → brittle failure

This confirms that Sample 1 has better load distribution and resistance to crack propagation.

### 2.1.7 Conclusion of Results

From the experimental investigation:

- Sample 1 shows superior mechanical performance
- Sample 2 exhibits brittle and weak characteristics
- Porosity and fiber distribution significantly influence the results

Therefore, Sample 1 is more suitable for structural and load-bearing applications.

"The mechanical performance of the composite is highly dependent on fiber distribution and porosity, where Sample 1 exhibited ductile behavior and higher strength compared to the brittle nature of Sample 2."

## 2.2 FLEXURAL TEST

The flexural test was performed according to ASTM D790 using a three-point bending setup.

### Specimen 1

Time	Displacement	Force	Flexure stress	Flexure displacement
(s)	(mm)	(kN)	(MPa)	(mm)
0	0	-0.0002	-0.0366	0
0.02	0	-0.0002	-0.049	0
0.04	0.0001	-0.0002	-0.0425	0.0001
0.06	0.0005	-0.0002	-0.0331	0.0005
0.08	0.0012	-0.0001	-0.0313	0.0012
0.1	0.0024	-0.0001	-0.0148	0.0024
0.12	0.0037	0	0.0101	0.0037
0.14	0.0049	0.0001	0.0295	0.0049
0.16	0.0061	0.0002	0.0334	0.0061
0.18	0.0072	0.0002	0.0431	0.0072
0.2	0.0084	0.0002	0.0497	0.0084
0.22	0.0096	0.0002	0.0482	0.0096
0.24	0.0109	0.0002	0.0434	0.0109
0.26	0.0122	0.0003	0.0597	0.0122
0.28	0.0134	0.0004	0.0775	0.0134
0.3	0.0145	0.0004	0.0814	0.0145
0.32	0.0157	0.0004	0.0838	0.0157
0.34	0.0169	0.0005	0.1067	0.0169
0.36	0.0181	0.0005	0.1101	0.0181
0.38	0.0194	0.0006	0.1227	0.0194
0.4	0.0205	0.0007	0.1424	0.0205
0.42	0.0217	0.0006	0.1402	0.0217

**Table 2.2**

### 2.2.1 Experimental Parameters

The specimens were prepared with the following dimensions:

- Span length (L) = 136 mm
- Width (b) = 14.2 mm and 15.1mm
- Thickness (d) = 10.6 mm

The test was performed using a universal testing machine, and load–displacement data were recorded throughout the experiment.

## 2.2.2 Stress and Strain Calculation (ASTM D790)

The flexural stress and strain were calculated using the standard equations:

- Flexural Stress:

$$\sigma = \frac{3FL}{2bd^2}$$

Flexural Strain:

$$\varepsilon = \frac{6Dd}{L^2}$$

Where:

- F = Applied load (N)
- L = Span length (mm)
- b = Width (mm)
- d = Thickness (mm)
- D = Deflection (mm)

## 2.2.3 Stress–Strain Behavior

The stress–strain curves for both samples were plotted based on the calculated values.

### Sample 1

- Exhibits a clear linear elastic region at the initial stage
- Gradual transition to plastic deformation
- Higher strain at failure indicates better ductility

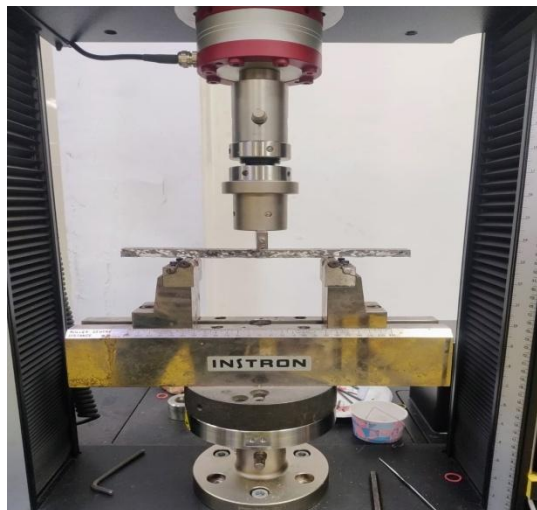


Fig. 2.2.3.a Flexural Test Specimen 1

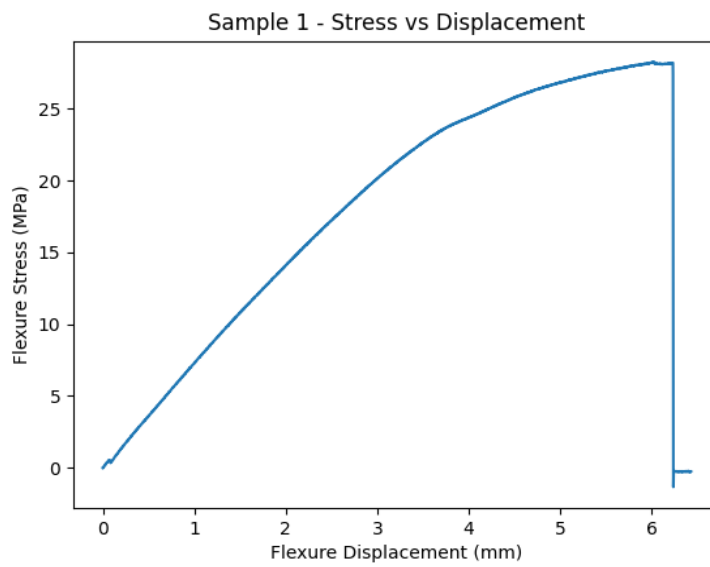


Fig. 2.2.3.b Sample 1 Stress vs Displacement

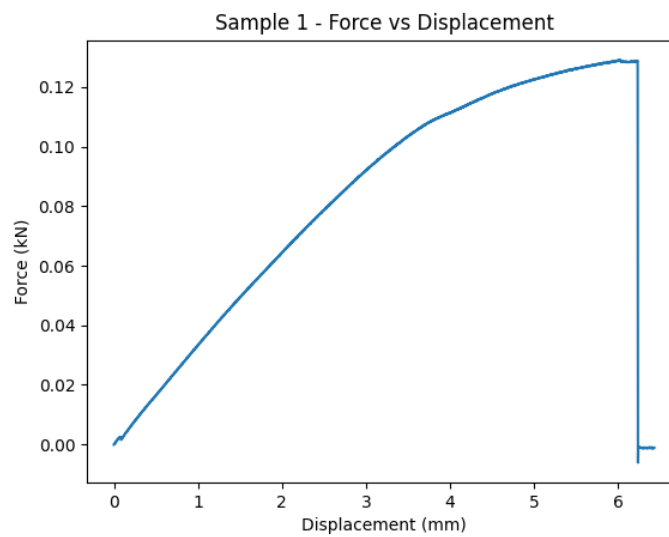


Fig. 2.2.3.c Sample 1 Force vs Displacement

## Sample 2

- Similar elastic behavior in the initial region
- Higher stiffness (steeper slope)
- Lower strain at failure indicates comparatively brittle behavior

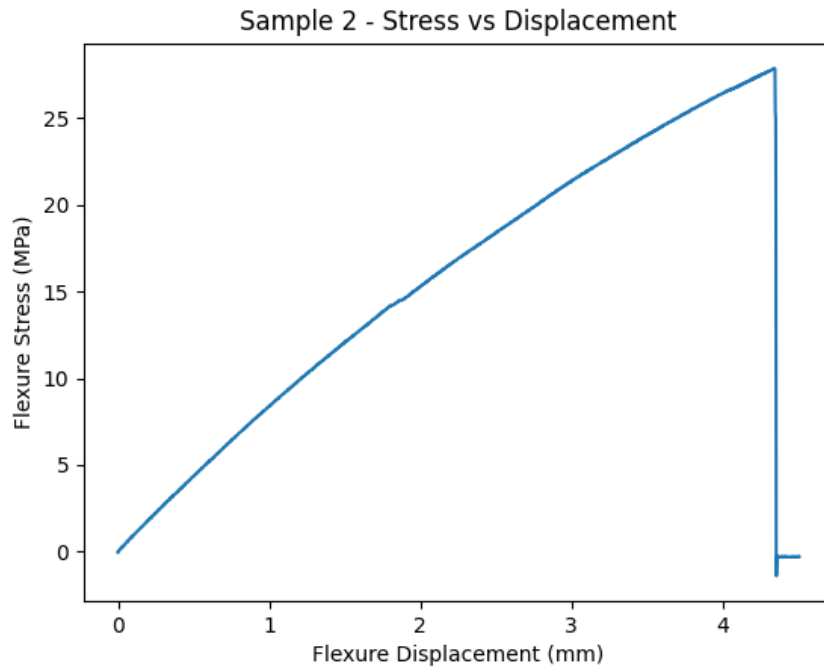


Fig. 2.2.3.d Sample 2 Stress vs Displacement

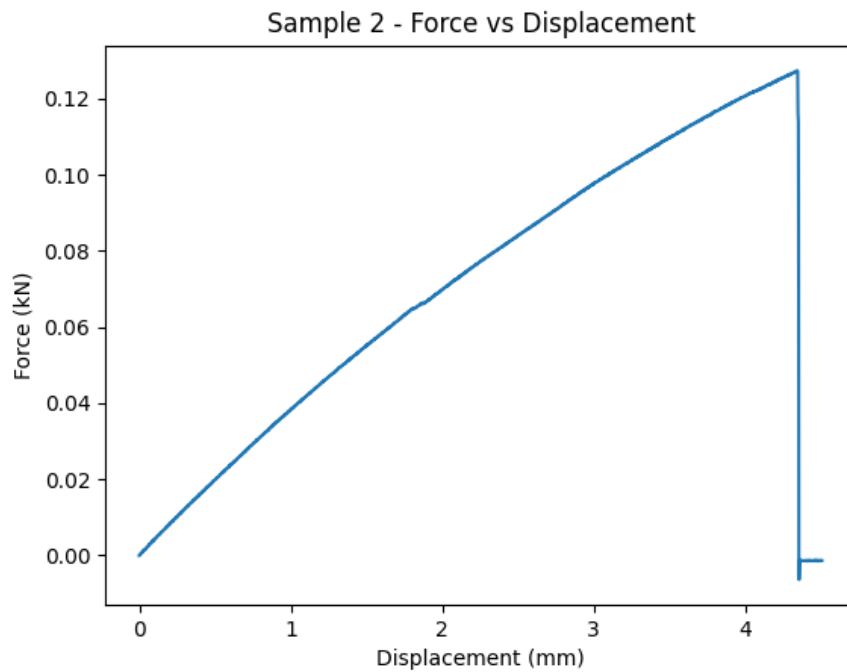


Fig. 2.2.3.e Sample 2 Force vs Displacement

### 2.2.4 Flexural Properties

Property	Sample 1	Sample 2
Flexural Strength (MPa)	28.26	27.88
Maximum Strain	~0.022	~0.015
Flexural Modulus (MPa)	1240	1497

Table 2.2.4

## 2.3 Discussion of Results

The results indicate that both samples exhibit comparable flexural strength, with values close to 28 MPa. This suggests uniformity in fabrication and consistency in material composition.

Sample 2 shows a higher flexural modulus, indicating that it is stiffer and resists deformation more effectively. However, Sample 1 demonstrates higher strain at failure, indicating better ductility and energy absorption capacity.

The stress–strain curves reveal that the material does not fail abruptly, which confirms that it does not behave as a purely brittle material. Instead, it exhibits moderate ductile characteristics, which are advantageous for structural and semi-structural applications.

The slight variation between the two samples may be attributed to:

- Non-uniform fiber distribution
- Presence of voids or porosity
- Variation in resin impregnation

These factors are common in composite fabrication and can influence mechanical properties.

**3.1 Conclusion:** My study focused on the development and mechanical characterization of a natural fiber-reinforced composite using water hyacinth fiber (*Eichhornia crassipes*) and epoxy resin as the matrix material. The primary objective of this research was to explore the feasibility of utilizing water hyacinth, an abundantly available aquatic waste material, as a reinforcing agent in composite applications and to evaluate its mechanical performance under tensile loading conditions.

From the experimental investigation, it is evident that water hyacinth fiber can be successfully incorporated into polymer composites as a reinforcing material. The use of such natural fibers offers a sustainable and environmentally friendly alternative to conventional synthetic fibers like glass and carbon fibers. Since water hyacinth is widely regarded as an invasive plant that negatively affects aquatic ecosystems, its utilization in composite materials not only provides engineering benefits but also contributes to environmental management and waste reduction.

The composite specimens were fabricated using the hand lay-up technique, which proved to be a simple, cost-effective, and suitable method for laboratory-scale production. This technique allows easy control over material placement and resin distribution without requiring sophisticated equipment. However, it was observed that the hand lay-up method has certain limitations, particularly the possibility of air entrapment, non-uniform fiber distribution, and the formation of voids within the composite structure. These defects can significantly influence the mechanical properties and overall performance of the material.

The tensile test results clearly indicate a significant difference in the performance of the two samples tested. Sample 1 exhibited a higher tensile strength of 6.91 MPa compared to Sample 2, which showed a tensile strength of 3.48 MPa. This improvement in strength can be attributed to better fiber–matrix bonding, more uniform fiber distribution, and reduced porosity in Sample 1. In contrast, the lower strength of Sample 2 is likely due to poor bonding, higher void content, and uneven fiber alignment, which reduce the efficiency of load transfer between the fiber and matrix.

In addition to tensile strength, the deformation behavior of the material was also analyzed using stress–strain curves. Sample 1 demonstrated the presence of a clear yield region followed by gradual plastic deformation before fracture. This behavior indicates ductile characteristics, where the material is capable of absorbing energy and undergoing deformation before failure. On the other hand, Sample 2 showed an abrupt failure without a noticeable yield point, indicating brittle behavior. Brittle materials tend to fail suddenly without significant deformation, which makes them less reliable in structural applications.

Another important observation from the stress–strain curves was the presence of a zig-zag pattern. This behavior is commonly observed in natural fiber composites and is mainly attributed to internal structural irregularities. The zig-zag nature of the curve indicates the occurrence of micro-cracks, fiber pull-out, and intermittent load drops during testing. These phenomena arise due to non-uniform fiber distribution, the presence of voids, and weak interfacial bonding between the fiber and matrix. Although such fluctuations may appear as irregularities in the graph, they are characteristic of natural fiber composites and reflect the progressive failure mechanism within the material.

The Young's modulus values for both samples were found to be nearly similar, indicating that the stiffness of the composites is relatively unchanged despite differences in strength. This suggests that while stiffness is primarily governed by the matrix material, the strength and toughness of the composite are more significantly influenced by factors such as fiber distribution, bonding quality, and internal defects. Therefore, improving these parameters is essential for enhancing the overall mechanical performance of the composite.

The failure mechanisms observed during testing further support the experimental findings. Sample 1 showed gradual failure with fiber pull-out, indicating better load sharing between the fiber and matrix. In contrast, Sample 2 exhibited sudden fracture, confirming weak bonding and poor structural integrity. These observations highlight the importance of proper fabrication techniques and material handling in achieving reliable composite performance.

Overall, the results of this study demonstrate that the mechanical properties of water hyacinth fiber-reinforced composites are highly dependent on factors such as fiber–matrix ratio, fiber orientation, distribution uniformity, and the presence of defects like voids and porosity. Proper control of these parameters can significantly improve the strength, durability, and reliability of the composite material.

In conclusion, the developed water hyacinth fiber-reinforced epoxy composite exhibits promising mechanical properties and demonstrates potential for use in low-load and semi-structural applications such as panels, boards, and non-critical structural components. With further optimization in fabrication techniques and material processing, this composite material can be developed into a viable and sustainable alternative for various engineering applications.

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