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Study On Mechanical Properties Of Stinging Nettles Based Fiber Reinforced Vinyl Ester Composites For Sustainable Engineering Applications

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Abstract
Natural fiber reinforced polymer composites are increasingly being explored as sustainable alternatives to conventional synthetic materials. In the present work, stinging nettle (Urtica dioica) fibers were used as reinforcement with vinyl ester resin as the matrix to develop a hybrid composite material. The fibers were first processed and cut into short lengths to ensure uniform distribution within the matrix. Composite laminates were then fabricated using the compression moulding technique at a temperature of 100 °C, with a composition of 60% vinyl ester resin and 40% stinging nettle fiber. The use of natural fibers such as nettle offers advantages including biodegradability, low density, and reduced environmental impact compared to conventional reinforcements. The developed composite is expected to provide a sustainable material option for various engineering and structural applications, while also promoting the utilization of renewable natural resources in polymer composite development.

Keywords: *Stinging nettle fiber, Vinyl ester resin, Mechanical characterization, Sustainable materials.*

1. Introduction

Natural fiber reinforced composites have gained significant importance in recent years due to their environmental advantages, low density, and cost-effectiveness. These materials are widely used in automotive, construction, and packaging industries as alternatives to synthetic fiber composites. Among various natural fibers, stinging nettle (Urtica dioica) has emerged as a promising reinforcement material due to its high cellulose content[1], good tensile properties, and biodegradability. It is a naturally available plant that grows widely and requires minimal processing, making it an economical and sustainable choice. Previous studies have focused on commonly used fibers such as jute, hemp, and flax. However, limited research has been conducted on the use of stinging nettle fiber in polymer composites, especially with vinyl ester resin as the matrix material. Therefore, the present study aims to develop and analyze a stinging nettle fiber reinforced vinyl ester composite using compression moulding technique and evaluate its mechanical properties under different loading conditions.

2. Materials and Methods:

2.1. Material

Stinging nettle fibers used in this study were procured from Himalayan Fibers (online supplier). The fibers were cleaned and dried to remove impurities before composite fabrication. Vinyl ester resin was used as the matrix material and was purchased from Covai Seenu & Company, Coimbatore, Tamil Nadu, India, along with methyl ethyl ketone peroxide (MEKP) as the catalyst and cobalt naphthenate as the accelerator. The composite was prepared with 60% resin and 40% fiber content, where the fibers were arranged in random orientation to ensure uniform distribution[2].

2.2. Composite Fabrication

The composite laminates were fabricated using the compression moulding technique. Initially, the mould surface was coated with a release agent (wax) to prevent sticking. The stinging nettle fibers were uniformly distributed within the mould cavity. The vinyl ester resin was mixed with catalyst and accelerator and poured over the fibers for proper wetting[11- [15]. The mould was then closed and subjected to a temperature of 100 C. The mould size used was 300 mm × 300 mm × 3 mm. After curing,

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the composite laminate was removed and cut into standard specimens according to ASTM standards for mechanical testing.

3. Mechanical Tests

3.1. Impact Test

3.1.1. Standard Followed

- Impact testing was conducted according to ASTM D256 using the Izod impact method.
- Specimen After and Before test is shown in Fig 2

3.1.2. Experimental Procedure

- A notched specimen was clamped vertically and struck by a pendulum hammer. The energy absorbed during fracture was recorded.
- Apparatus is shown in Fig 1

3.1.3. Impact Behaviour of Hybrid Composite

- Stinging nettle fibers contribute to energy absorption
- Uniform fiber distribution improves impact resistance[7]- [10]
- Matrix bonding helps resist crack propagation
- Composite shows stable impact behaviour across specimen sizesmulti-directional orientation provides balanced strength.

3.2.Tensile Test

3.2.1. Standard Followed

The test was performed according to ASTM D638 standard for polymer matrix composites.

3.2.2. Specimen Preparation

The composite laminates were cut into standard dog-bone shaped specimens as per ASTM dimensions. Care was taken to ensure:

- Uniform thickness
- Smooth edges to prevent premature failure
- Fiber alignment maintained during cutting
- Specimens were conditioned at room temperature before testing[16].- [17]
- Specimen After and Before test is shown in Fig 4.

Figure 1 Experimental Setup for Precision Mechanical Measurement System

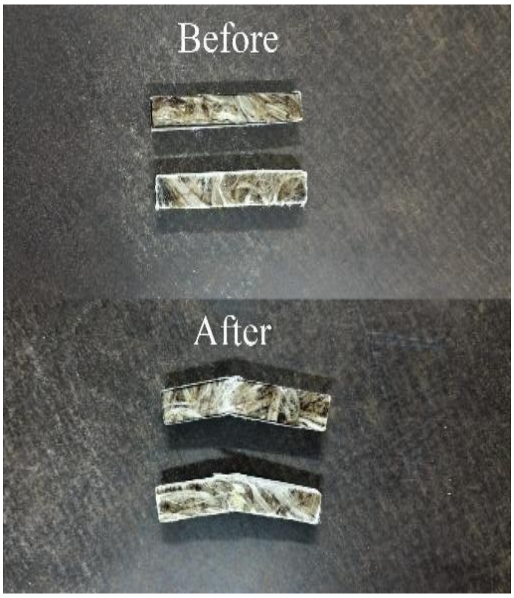

Figure 2 Pre- and Post-Processing Comparison of Test Specimens

3.2.3. Behaviour of Hybrid Composite Under Tensile Load

Fibers carry major load after matrix deformation
Good interfacial bonding improves strength
Failure occurs due to fiber breakage and pull-out
Increasing thickness improves load-bearing capacity

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Figure 3 Experimental Setup for Tensile Strength Analysis

Figure 4 Specimen Condition Before and After Tensile Testing

3.3. Flexural Test

3.3.1. Standard Followed

- The test was conducted as per ASTM D790 using a three-point bending configuration.
- Specimen Before and After test is shown in Fig 6

3.3.2. Experimental Procedure

- The specimen was placed on two supports and load was applied at the center until fracture.

3.5.Compression Test

3.5.1. Standard Followed

During bending:

- Upper surface experiences compressive stress
- Lower surface experiences tensile stress
- Neutral axis remains stress-free
- Failure initiates either from tensile cracking or compressive buckling of fibers.
- Apparatus is shown in Fig 5

3.3.3. Flexural Behaviour of the Hybrid Composite

In the Cyperus Pangorei / Jute composite:

- Upper layer undergoes compression
- Lower layer undergoes tension
- Fiber reinforcement improves stiffness
- Good bonding delays crack initiation

Figure 5 Flexural Strength Measurement Using UTM

Figure 6 Specimen Appearance Before and After Flexural Testing

3.4.

- The test was performed according to ASTM D695 standard.

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- Specimen Before and After test is shown in Fig 7

Table 1 Sample Dimension

SAMPLE DIMENSION	SAMPLE	IMPACT TEST BREAKING POINT (kJ/m^2)	TENSILE TEST BREAKING POINT (MPa)	FLEXURAL TEST BREAKING POINT (MPa)	COMPRESSION TEST BREAKING POINT (MPa)
3 mm	1	362.96	18.42	38.21	46.85
	2	362.91	17.63	36.94	44.72
	3	363.39	19.18	39.56	47.93
6 mm	1	362.96	24.86	46.75	52.64
	2	362.91	23.42	44.89	50.38
	3	363.39	26.17	48.92	53.71
9 mm	1	362.96	30.58	55.64	56.92
	2	362.91	28.42	53.81	54.73
	3	363.39	32.11	57.48	58.36

Figure 7 Damage and Fracture Analysis After Compression Loading

3.5.2. Experimental Procedure

The specimen was placed between compression platens and axial compressive load was applied until failure

3.5.3. Compression Behaviour of Hybrid Composite

- Fibers resist buckling
- Matrix supports lateral stability
- Good dispersion increases strength
- Hybrid bonding improves resistance

4. Results and Discussion

4.1. Impact Test Results

The impact test results indicate that the energy absorption remains nearly constant across all specimen dimensions, with values around 362–363 kJ/m². This suggests that the composite has uniform resistance to sudden loading. The stable behaviour may be attributed to consistent fiber distribution and effective bonding between the stinging nettle fibers and vinyl ester matrix.

4.2. Tensile Test Results

The tensile strength increases with increasing specimen dimension. The 3 mm specimen shows

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values around 17–19 MPa, while the 6 mm specimen ranges between 23–26 MPa [3]- [6]. The 9 mm specimen exhibits higher strength values around 28–32 MPa. This improvement is due to better load transfer between fiber and matrix and increased material volume resisting deformation.

4.3. Flexural Test Results

The flexural strength also increases with specimen dimension. The 3 mm specimen shows values around 36–39 MPa, while the 6 mm specimen shows values around 44–48 MPa. The 9 mm specimen reaches values up to 57 MPa. This indicates improved bending resistance due to enhanced fiber reinforcement and structural integrity.

4.4. Compression Test Results

The compressive strength increases from approximately 44–47 MPa for 3 mm specimens to around 54–58 MPa for 9 mm specimens. This trend indicates that thicker specimens provide better resistance to compressive loads. The improvement is attributed to reduced fiber buckling and improved stress distribution within the composite.

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