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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF MECHANICAL PROPERTIES ON JUTE-CARBON FIBER REINFORCED HYBRID COMPOSITES.

***K.Geetika, Dr. P.K.Mohanta, Dr.B.D.Y. Sunil**

Institute of Aeronautical Engineering.

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***Corresponding Author: K.Geetika,**
Institute of Aeronautical Engineering.

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ABSTRACT

Composite materials are widely used now a days due to their superior strength, hardness, and light weight nature compared to conventional materials. This study focuses on the development of a hybrid composite using carbon fiber reinforced polymer and jute fiber, fabricated through the hand layup technique. Carbon fiber provides exceptional tensile strength and stiffness, while jute fiber a natural and cost-effective reinforcement, enhances the composite sustainability. The fabrication involves layering four jute and three carbon fiber plies with its corresponding hardening polyester resin in 10:1 ratio, ensuring proper adhesion and minimizing defects such as air bubbles. The mechanical properties of the hybrid composite are assessed through tensile and flexural tests to evaluate its strength and durability. Furthermore numerical simulations using ANSYS Software are conducted, and the results are compared with theoretical calculations to validate the composite structural performance. This research aims to explore the potential of CRFP-Jute hybrid composites for aerospace, automotive, and structural applications, where a balance between strength, weight reduction, and sustainability is essential.

KEYWORDS: Carbon fiber reinforced polymer, Jute fiber, Epoxy Resin.

INTRODUCTION

A composite material is formed by combining two or more distinct substances to create a new material with enhanced properties not achievable by the individual components alone. In recent years, jute and carbon fiber-reinforced composites have gained significant attention across various industries such as automotive, aerospace, textiles, and construction, as alternatives to traditional materials like metals.

Jute, a natural plant fiber, and carbon fiber, a high- performance synthetic fiber, are increasingly being used in hybrid composite systems. These fiber-reinforced composites offer several advantages including a high strength-to-weight ratio, low density, cost-effectiveness, and improved environmental sustainability. Jute, in particular, contributes to biodegradability and recyclability, while carbon fiber adds superior mechanical strength and durability.

Applications of jute and carbon fiber composites span across the automotive sector for lightweight body parts, in construction for insulation panels, in aerospace for interior components, and in textiles for technical fabrics. These materials exhibit excellent acoustic insulation and mechanical resistance. Jute fibers also enhance thermal insulation due to their low density and high porosity, making them ideal for energy-efficient applications.

The mechanical and physical performance of these composites is influenced by the chemical composition and quality of the fibers, which depend on factors such as processing techniques, environmental conditions, and cultivation methods. Treatments like fiber dipping improve the tensile strength, while fiber uniformity and proper alignment are critical for maintaining structural integrity. Defects within the fiber structure can significantly reduce performance. various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

Carbon fiber is a high-performance material made primarily from carbon atoms bonded in long chains, typically produced by heating a precursor like polyacrylonitrile (PAN) to high temperatures to form strong, lightweight fibers. These fibers are woven into fabrics or combined with resins to create carbon fiber composites that are significantly lighter than steel while being up to five times stronger. Known for its exceptional strength-to-weight ratio, carbon fiber is extensively used in aerospace, automotive, and sports industries to enhance performance, reduce weight, and improve fuel efficiency. In aerospace, it is used for components like wings and fuselages, while in the automotive sector, it contributes to lighter, fuel- efficient vehicles. Carbon fiber is also highly resistant to corrosion and fatigue, making it suitable for use in harsh environments, and it exhibits excellent thermal and electrical conductivity, expanding its applications in electronics and renewable energy, such as wind turbines and electric vehicles. Available in types like ultra-high modulus and high elastic modulus, carbon fiber offers tailored properties for different engineering needs. Although its production remains energy- intensive and costly, advancements in manufacturing and recycling are gradually reducing costs, paving the way for broader adoption. With growing emphasis on sustainability and energy efficiency, carbon fiber continues to play a transformative role across various industries.

MATERIALS AND METHODOLOGY

In this research Jute fiber, Carbon fiber and Epoxy resin, are used. The first two materials are reinforcements for the hybrid composite and the last material is the matrix for the hybrid composite.

Jute is a long, soft, and shiny bast fiber derived mainly from *Corchorus capsularis* (white jute) and *Corchorus olitorius* (tossa jute), both belonging to the Malvaceae family. It grows best in tropical and subtropical regions with high humidity, moderate rainfall, and temperatures between 24°C and 37°C. The fast-growing annual plants reach 2–4 meters in height and have lanceolate leaves with yellow flowers. The fiber is extracted from the stem's phloem through retting, a microbial process that separates it from the woody core. Jute is valued for its biodegradability, durability, and high tensile strength, making it a sustainable alternative to synthetic fibers. While it is largely self-pollinating, some cross-pollination occurs via wind and insects. Genetic improvement efforts focus on fiber quality, yield, disease resistance, and environmental adaptability, using methods such as pure-line selection, hybridization, and mutation breeding. Advances in biotechnology, including molecular markers and genetic engineering, are also being pursued to enhance jute's fiber properties, drought tolerance, and pest resistance.

Fig. 1 Jute Plant.

Fig.2 Jute Fiber.

Carbon fiber is a high-performance material made primarily from carbon atoms bonded in long chains, typically produced by heating a precursor like polyacrylonitrile (PAN) to high temperatures to form strong, lightweight fibers. These fibers are woven into fabrics or combined with resins to create carbon fiber composites that are significantly lighter than steel while being up to five times stronger. Known for its exceptional strength-to-weight ratio, carbon fiber is extensively used in aerospace, automotive, and sports industries to enhance performance, reduce weight, and improve fuel efficiency. In aerospace, it is used for components like wings and fuselages, while in the automotive sector, it contributes to lighter, fuel- efficient vehicles. Carbon fiber is also highly resistant to corrosion and fatigue, making it suitable for use in harsh environments, and it exhibits excellent thermal and electrical conductivity, expanding its applications in electronics and renewable energy, such as wind turbines and electric vehicles. Available in types like ultra-high modulus and high elastic modulus, carbon fiber offers tailored properties for different engineering needs. Although its production remains energy- intensive and costly, advancements in manufacturing and recycling are gradually reducing costs, paving the way for broader adoption. With growing emphasis on sustainability and energy efficiency, carbon fiber continues to play a transformative role across various industries.

Fig.3 Carbon Fiber.

TABLE.I PROPERTIES OF JUTE AND CARBON FIBER.

S.No	Property	Jute	Carbon
1	Density (g/cm^3)	1.3–1.5	1.6–2.0
2	Tensile Strength (Mpa)	200-800	3000–6000
3	Elastic Modulus (Gpa)	10-30	230–600
4	Elongation (%)	1.5–1.8	1.2–1.8

FABRICATION OF HYBRID SPECIMEN

Composite laminates can be fabricated using various techniques, including hand lay-up, autoclave molding, filament winding, pultrusion, resin transfer molding, and compression molding. The selection of the fabrication method often depends on the desired shape, application, and performance requirements of the composite. For instance, filament winding is ideal for producing cylindrical components like chemical storage tanks and pipes, while autoclave molding is employed for manufacturing high-performance parts with minimal void content and superior structural integrity. Resin transfer molding is particularly suitable for automotive components where rapid, small-batch production is required. In this study, compression molding was chosen due to its effectiveness in producing high- quality components with precise dimensional tolerances, especially in low-volume production. This process utilizes matched dies, ensuring uniformity in mechanical properties. Once the fabrication method was selected, the mold was prepared using suitable materials such as wood, plastic, or metal, depending on factors like curing temperature, pressure, and production volume. Jute and carbon fibers were chopped and accurately weighed using a digital balance, followed by thorough mixing with epoxy resin LY 556 and hardener HY 951 for a minimum of five minutes to ensure proper consistency. The prepared fiber-resin mixture was then carefully placed into the mold based on the specified fiber weight fractions. The assembly was left to cure undisturbed for 24 hours. After curing, the mold was opened, and the hybrid jute/carbon composite laminate was demolded, cut according to ASTM standard dimensions, and made ready for subsequent mechanical testing.

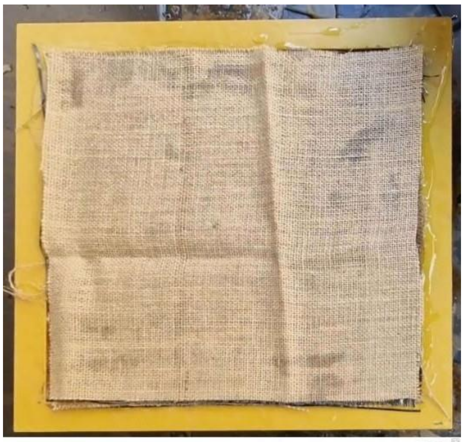


Fig. 4 Fibers arranged in the mold.

TABLE.II FIBERS VS MATRIX WEIGHT FRACTION

Hybrids	bers weight fraction		trix=weight fraction
	Jute	Carbon	Epoxy
H1	0.35	0.25	0.4

Fg.5 Cutting of Specimen

To accurately evaluate the properties of a material, especially its mechanical characteristics, the specimens must be prepared according to recognized standard guidelines such as ISO or ASTM. These standards ensure that the samples are cut to specific dimensions suitable for reliable and reproducible testing. Among them, ASTM (American Society for Testing and Materials) is one of the most widely adopted standards in materials research. In this study, ASTM D3039 and ASTM D790-03 were selected for testing purposes. These standards are commonly used by researchers for evaluating composite materials, with ASTM D3039 applied for tensile testing and ASTM D790-03 for flexural testing. Their widespread acceptance ensures consistency and comparability of results across different studies.

TABLE III ASTM STANDARD OF SAMPLES

MECHANICAL PROPERTIES	ASTM STANDARD
Tensile strength	ASTM D3039
Flexural (bending strength)	ASTM D 790-03

Fig.6 Specimens are cutted according to ASTM Standards.

DESIGN ANALYSIS STUDY

CATIA (Computer-Aided Three-dimensional Interactive Application), developed by Dassault Systèmes, is a powerful multi-platform software suite that integrates CAD (Computer- Aided Design), CAM (Computer-Aided Manufacturing), and CAE (Computer-Aided Engineering) functionalities. Widely used in industries such as aerospace, automotive, and consumer products, CATIA allows users to design, simulate, analyze, and manufacture complex products within a single environment. The software supports solid modeling, surface design, assembly creation, and technical drafting, offering features like bi- directional associativity—where changes in 3D models are automatically reflected in 2D drawings and vice versa. Written in C++, CATIA runs on both Unix and Windows operating systems. Among its core workbenches are Part Design, used for solid modeling; Sketcher, for creating constrained 2D profiles; Wireframe and Surface Design, for advanced geometries; Assembly Design, for defining part relationships; and Generative Drafting, for producing detailed technical drawings. In the Part Design workbench, modeling typically begins with 2D sketches that serve as the foundation for 3D features. These sketches are created on reference planes and can be easily edited by modifying dimensional constraints, making CATIA a highly flexible and robust tool for engineering design and product development.

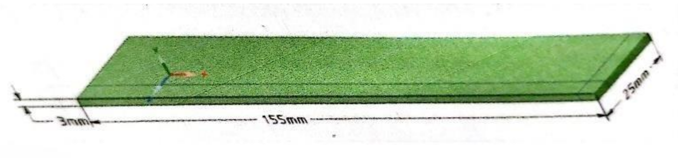


Fig.7 CATIA design of rectangular section.

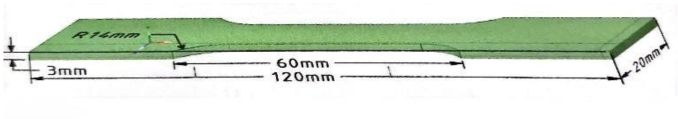


Fig.8 CATIA design of dog-bone section

ANSYS is a comprehensive finite element analysis (FEA) software used for simulating structural, thermal, modal, and buckling behavior of materials and components. It supports geometry import from CAD tools and enables efficient evaluation of product performance with reduced reliance on physical testing. ANSYS uses a vast library of elements and material models for solving both linear and nonlinear problems across various engineering fields. Structural analysis typically starts with selecting the Static Structural system, defining material properties in the Engineering Data section, and creating or importing geometry. Meshing involves generating a finite element mesh, adjustable from coarse to fine, using 3D tetrahedral elements to balance accuracy and computation time. To perform structural analysis in ANSYS, begin by selecting "Static Structural" from the Analysis Systems menu to assess displacements, stresses, and strains under static loads. Define the material and its properties in the Engineering Data section, either using the default (e.g., Steel) or custom materials. Geometry can be created using Design Modeler or imported from CAD software. Meshing is done by generating a default 3D tetrahedral mesh in the Mesh section, with options to adjust mesh density (Coarse, Medium, Fine) for balance between speed and accuracy. To view axial (normal) stress results, switch to ISO view, click "Normal Stress" in the Tree Outline, and change the display to Smooth Contours for better visualization.

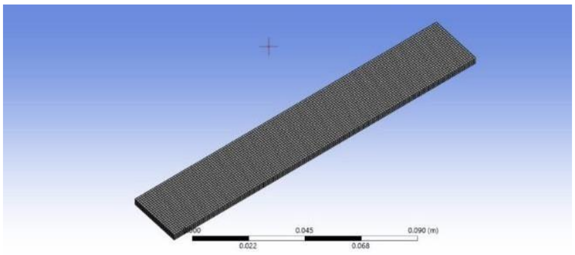


Fig.9 Mesh in ANSYS for Flexural test.

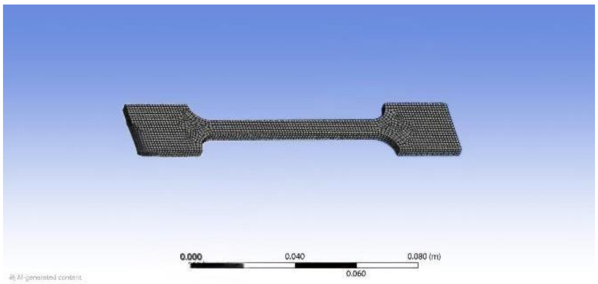


Fig.10 Mesh in ANSYS for Tensile test

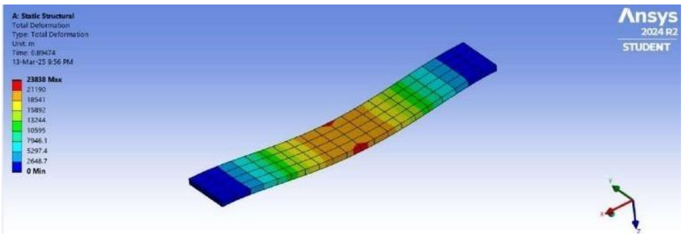


Fig.11 Contour in ANSYS of flexural test

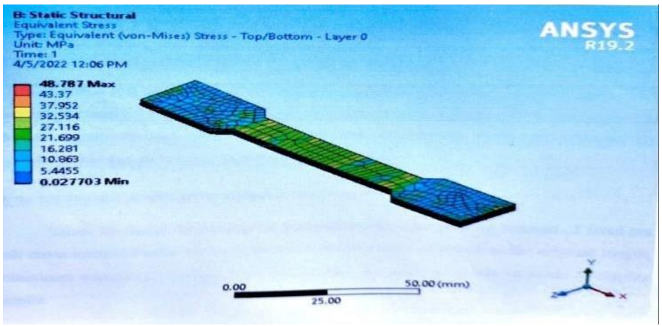


Fig.12 Contour in ANSYS of tensile test

RESULTS AND DISUSSION

Tensile test Results.

The tensile test is a key method for evaluating the mechanical behavior of materials, especially in engineering applications. In this study, specimens were fabricated in accordance with ASTM standards and subjected to a uniaxial tensile load. Three hybrid jute/carbon composite samples were prepared with weight fractions—40%, 20%, and 40% of jute/carbon fibers, respectively—while maintaining a constant 40% epoxy matrix content across all samples.

Stress vs elongation of hybrid composites.

During tensile testing, stress and elongation (strain) values were recorded using a universal testing machine. However, variations in test conditions, environmental factors such as temperature, manual fabrication inconsistencies from the compression molding process, and human error led to slight differences in the measured values. To ensure consistency and reliability, the average tensile strength values of the longitudinal specimens were considered for analysis in this study.

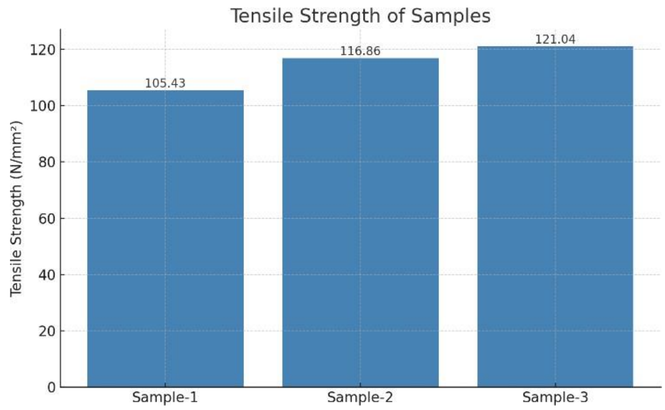


Fig.13 Longitudinal tensile strength for hybrid laminates.

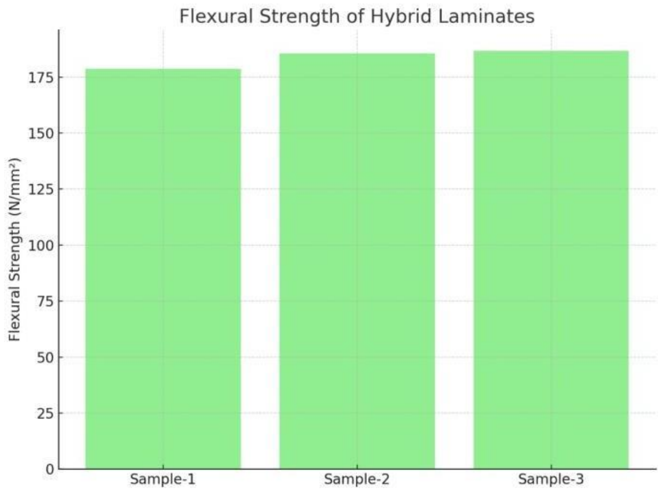


Fig.14 Flexural strength for hybrid laminates

The test results are plotted in fig 15,16. The plots make it evident how jute fiber affects the hybrid composite. The tensile strength is at its highest value (about 121.043 N/mm2) with increase of jute fiber, while the lowest weight fraction of carbon fiber, i.e., highest weight fraction of jute fiber, has the lowest tensile strength. In other words, the tensile strength decreases with decrease in the weight fraction of carbon fiber.

The tensile strength results of the three samples of the composites are shown in Fig 13. From the bar graphs of the tensile strength results, the weight fraction of jute fiber mixed to carbon fiber did affect the longitudinal tensile strength of the Jute/carbon hybrid samples. The tensile strength improved with increase in jute fiber weight fraction and decrease of weight fraction of the E-glass fiber.

The maximum longitudinal tensile strength was 121.043 N/mm2 which occurred for the composites of 35% Jute and 25
% Carbon with a 40% epoxy matrix. The minimum longitudinal tensile strength was 105.43 N/mm. The weight fraction of the matrix (epoxy) was kept constant at 40% throughout the test.

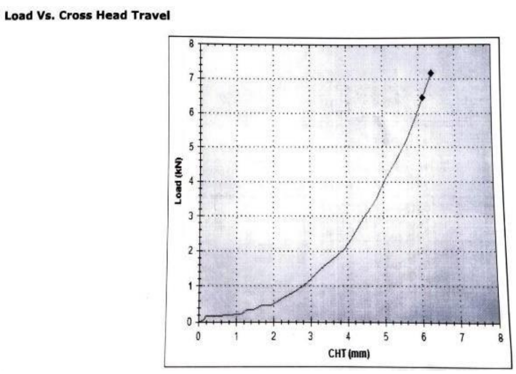
Flexural Test Results.
The ability of a material to tolerate bending forces applied perpendicular to its longitudinal axis is known as its flexural strength. For the three-point bending test, three specimens for three different weight fractions of Kenaf and sisal fiber with a constant weight fraction of matrix (epoxy) were prepared by manual compression molding process as per ASTM D790-03 standard.

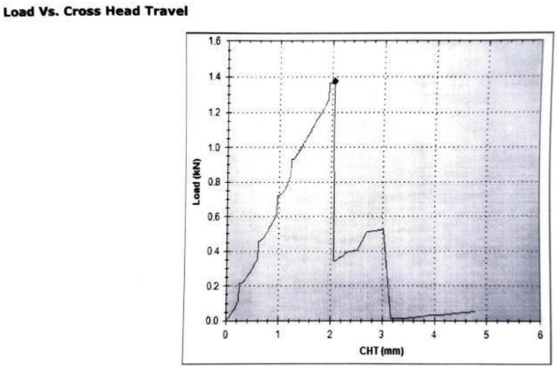
The flexural properties of Jute/Carbon hybrid reinforced composites of three samples of weight fraction are shown in Figure 14. It is observed from the plots that the flexural characteristics of the composites are affected by the weight fraction of Jute fiber. The Carbon hybrid laminates have better flexural properties than all the pure natural laminates, and the properties seem to be increasing with the addition of the weight fraction of Carbon fibers.

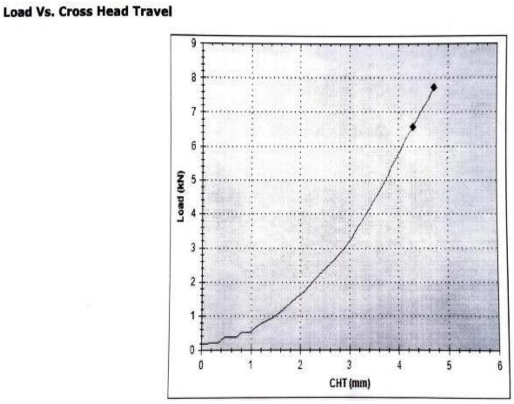
The plots in Figure 14 also shows that the maximum flexural strength is 186.82 N/mm2, while the flexural strength of hybrid composites with another sample is found to be about 178.73 N/mm2. From these results, we conclude that flexural (bending) stress increases.

TABLE.IV MECHANICAL PROPERTIES OF JUTE/CARBON HYBRID COMPOSITE.

Sample	Tensile strength (N/mm^2)	Flexural strength (N/mm^2)
1	105.431	178.73
2	116.865	185.53
3	121.043	186.82







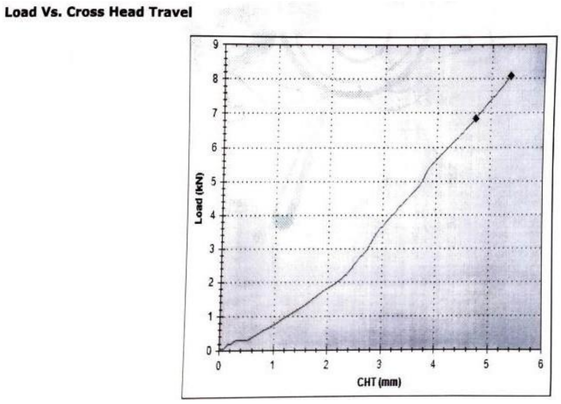
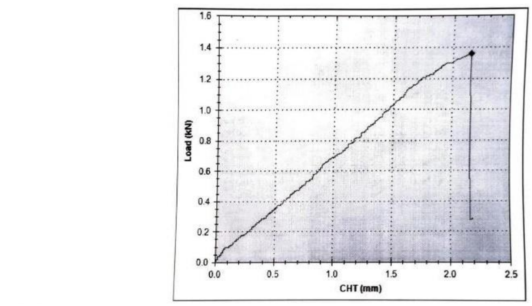


Fig. 15 Load vs elongation for weight fractions of Jute/Carbon hybrid composites.



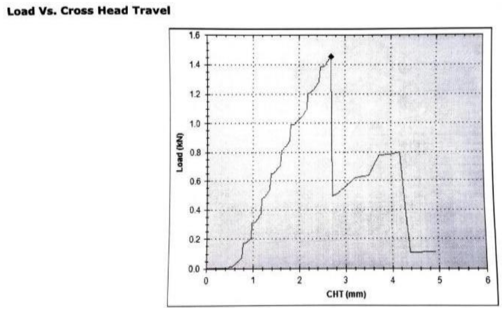


Fig.16 Load vs elongation for weight fractions of Jute/Carbon hybrid composites.

TABLE. V COMPARISION ON NUMERICAL AND THEORITICAL RESULTS

Analysis	**Tensile (N/mm²)**	**Flexural (N/mm²)**
Numerical	92.35	144.45
Theoretical	105.431	178.73

CONCLUSION

Basically, here we have compared the numerical and theoretical values of Jute/Carbon hybrid composites. I have analyzed that Numerical value of tensile strength is about 92.35 N/mm² where as the theoretical value is about 105.431 N/mm². Similarly, I have also compared for Flexural test where the results obtained for numerical are 144.45 N/mm² and for theoretical is 178.73 N/mm².

This article investigates the mechanical properties (tensile and flexural) of Jute/carbon hybrid reinforced epoxy matrix composites. The ultimate tensile strength, tensile modulus strength of samples prepared as per ASTM standards were obtained experimentally. Based on the experiments conducted (tensile and flexural) the following conclusions can be drawn:

- In this project I have designed, analyzed and Fabricated the Jute/Carbon Hybrid laminated composite fiber.
- The variation of tensile and flexural tests on Jute/carbon are modeled in the CATIA V5 and analyzed in the ANSYS software also designed and analyzed the mechanical properties as a reinforced composite material.
- From the computer analysis by conducting the tensile and flexural tests on the composite material, the results of deformation obtained as 92.35 N/mm² and
- 144.45 N/mm².
- In experimental analysis I have fabricated the Jute- carbon hybrid laminated fiber composite in 4:3 weight ratio and resin and hardener in 10:1 weight ratio and prepared using Hand lay-up technique.

- The shapes are cutted according to ASTM standards and are tested for mechanical properties of materials for tensile and flexural tests.
- From the Experimental analysis I have researched that minimum value is 105.431 N/mm² and the maximum value is 121.043 N/mm² are tested under Tensile test.
- The minimum value and maximum value that are tested under Flexural test are 178.73 N/mm² and 186.82 N/mm² respectively.

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