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EXPLORING THE SYNERGY OF NATURAL FIBER REINFORCEMENT IN COMPOSITE MATERIALS: A STUDY ON JUTE-BASED COMPOSITES USING FINITE ELEMENT ANALYSIS

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ABSTRACT

In recent times, composite components based on natural fibers/fillers are becoming more prevalent owing to their lightweight nature, simplicity of acquisition, environmental sustainability, and enhanced stiffness and strength. Finite Element Analysis (FEA) is implemented in this work to assess the tensile characteristics of jute-based composites at different filler content compositions (0, 2.5, 5, 7.5, 10, and 12.5 wt.%). The study validates the efficacy of FEA in forecasting material changes under various situations by correlating computational results with experimental information using ANSYS R121 software. The findings show that, up to a certain point, the tensile strength of jute particle composites (JPC) increases as the filler content rises; beyond that, a decrease in strength is seen because of a decreased stress transfer efficiency. In applications that need for lightweight and biodegradable materials, the research emphasizes jute's potential as a competitive substitute for synthetic fibers. Additionally, a fifth-order polynomial model is created to calculate composite strength based on strain rates and particle proportions, enabling engineers and researchers to choose and build materials more effectively. This study highlights the importance of natural fiber composites in developing sustainable material solutions for a range of industrial applications and offers insightful information on their mechanical properties.

Keywords: Jute particulates, Mechanical strength, FEM, ANSYS.

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I. Introduction

The automotive and construction industries face the most formidable challenges in weight minimization and achieving improved specific strength and stiffness. The drop in mass enhances effectiveness with relation to fuels. As a consequence, consumers may explore replacing conventional substances with innovative materials with an excellent strength-to-weight proportion appropriate for their intended uses [1, 2]. At this moment, the composite element entered into the scene, constituted of two or more components combined macroscopically. The properties of the composite, which include low mass, resistant to corrosion and ideal strength, render it more acceptable to be employed in the automotive, aviation and numerous scientific fields [3]. The composite incorporating synthetic fibers such as carbon, Kevlar, and glass exhibits remarkable characteristics utilized across multiple industrial domains. However, these synthetic materials still don't meet expectations for recycling and biodegradability due to a few properties [4]. Natural fiber-based composites (NFC) are used instead of synthetic fiber-based composites (SFC) in the development of biodegradable products as they are more lightweight, cheaper to produce, and exhibit a greater modulus-to-strength relation. NFC offers considerable resistance to damage and significant ability to retain moisture along with the previously mentioned characteristics.

Despite their long-standing use in applications like housing and textiles, the popularity of NFCs has waned due to the superior mechanical properties of synthetic alternatives. However, with increasing awareness of environmental issues related to synthetic waste and the quest for sustainable materials, interest in NFCs has been revitalized. Recent advancements have shown that the mechanical properties of NFCs can now rival those of SFCs, paving the way for their application in more demanding environments [5-7].

The utilization of natural fibers in the creation of polymeric materials has been the subject of increased research attention. Research has shown that composite materials reinforced with natural fibers are capable of achieving mechanical characteristics that are comparable to those of conventional synthetic materials [8]. Longer fiber lengths, for example, dramatically increased fracture toughness in composites made of bamboo fiber, according to research done by Khan et al [9]. Comparably, Rosa et al.'s study of quasi-unidirectional flax-fiber-based composites revealed improved mechanical performance above that of unprocessed polymer samples. Ahmed et al. discovered that isothalic polyester materials based on jute had superior mechanical properties over traditional polyester jute composites [10, 11].

Jute is a very attractive substitute for lignocellulosic fillers in a variety of applications. It is sourced from the swiftly expanding and environmentally friendly jute plant. Jute is an inexpensive agricultural resource with amazing possibilities for composite materials. Jute particulates are a great option for producing high-quality products since they have benefitted such a low disintegration rate [12, 13]. The production of lighter vehicle components, building boards, panels, and defensive gear are only a few of the areas where the effectiveness of jute particles composites (JPC) is shown [14]. A numerical analysis of NFC was conducted by

Balasubramanian et al., and the findings were contrasted with experimental data. Additionally, the authors stated that the outstanding agreement between the numerical and experimental results is shown by the little 2%–6% difference [15]. According to Cuan-Urquizo et al., computational methods for determining the mechanical strength of composites have also produced results that are comparable to experimental results, with a little variance of around 6.6% [16]. By adding more variables using the model update technique, Petrone and Meruane's numerical study of the mechanical properties of flax/polyethylene NFCs revealed that, even after upgrading two factor sections, the findings might be improved [17]. Xiong et al. assessed the micromechanical characteristics of flax/polyoxymethylene NFCs using the representative volume element (RVE) simulation approach. The results showed that the twist configuration of the fiber significantly affects the elastic properties of this NFC [18].

In order to assess the tensile features of jute-based composites under different filler content compositions, Finite Element Analysis (FEA) is used in this work. This study attempts to offer a thorough knowledge of how various weight fractions of jute powder affect these composites' mechanical performance by using ANSYS R121 software. The results will aid in the current discussion on sustainable materials and provide engineers and researchers with useful information for material selection and design procedures.

II. COMPOSITE DESCRIPTION & COMPUTATIONAL METHODOLOGY

ANSYS R121 is employed during this research for evaluating the tensile capacity of compounds with various jute particulate weight proportions (0, 2.5, 5, 7.5, 10, 12.5 wt. %). The computationally measures are subsequently contrasted with the experimentally verified amounts previously examined by Mahakur et al. [19]. The outcomes recorded at single strain rate i.e., 1 mm/min are presented in Table 1.

Table 1: Experimental outcomes of composites at varied particulate proportions [19]

Filler wt.%	**Tensile strength (MPa)**
0%	36.09
2.5%	41.9
5%	49.54

7.5%	45.25
10%	41.77
12.5%	24.32

The Finite Element Method (FEM) is utilized for computing the probable solution for the specified boundary region. The approach fundamentally consists of three essential steps: first, the desired geometry has been separated into smaller sections known as meshing; secondly, the appropriate material is allocated; and finally, the requisite boundary criteria are applied to the structure in order to derive the responses associated with the specified parameters [20].

This research uses ANSYS R121 to perform FEA on a sample that has been generated in CatiaV5R21. The specimen (shown in Figure 1(a)) has measurements of 63.5 mm x 10 mm x 3.2 mm. And after the designing of the specimen, it has been transported to ANSYS workbench via IGES format. After this, the tensile test is carried out using explicit dynamics of the physics kind. The existence of properties and features of materials such as density, Poisson’s ratio, and Young’s modulus are established through the concepts of composite mechanisms [21]. Table 2 lists the material attributes taken into account throughout the study. Depending on the various proportions of jute particulates, Young's modulus data change. The item being studied is subjected to boundary scenarios, where one portion is fixed and the other is subjected to a velocity. The framework meshes using quadratic meshing; Figure 1(b) shows the 21,056 elements and 50,595 nodes that make up the model. In order to get an improved stress-gradient across components, quadratic meshing using a maximum resolution of 7 is employed.

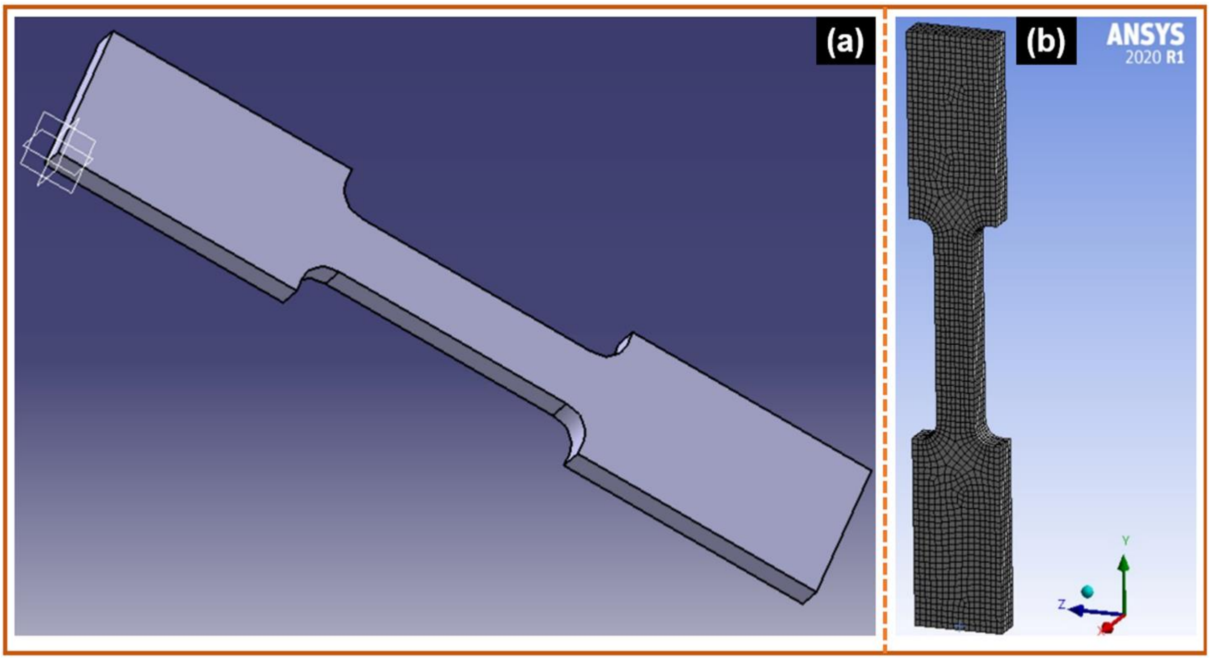

Fig. 1 (a) Specimen model drawn at CatiaV5R21, and (b) Quadratic meshing performed on the composite model specimen using ANSYS

Table 2: Material engineering characteristics at varied particulate proportions [22]

Composite Sample	**Density (g/cm^3)**	**Young's Modulus (MPa) @ 1 mm/min**	**Poisson's ratio (υ)**
0.0 wt.%	1.2	260	0.25
2.5 wt.%	1.14858	380	
5.0 wt.%	1.10138	430	
7.5 wt.%	1.05792	320	
10.0 wt.%	1.01776	290	
12.5 wt.%	0.98052	190	

III. RESULTS AND DISCUSSIONS

In certain boundary conditions, which involves the application of velocity at 1 mm/min at one side of the object being studied and fixing of the object at the opposite end, the tensile feature of jute particles composites (JPC) with considered weight proportions (0, 2.5, 5, 7.5, 12.5 wt.%) are analyzed. In order to explore the influence that this rate has on the tensile ability of the materials that have been created, which may show its developing uses in a variety of places. Moreover, such a classification would be of great use in gaining an understanding of their applicability for situations that include dynamic applications.

In this particular instance, the models are built by making the assumption that the cross-sectional profile of the material is homogeneous. Taking into consideration the same boundary circumstance that was used in the actual time assessment, the findings of the tensile tests that were performed at cross-head speed of 1 mm/min for composite materials at all considered weight proportions are demonstrated in Figure 2.

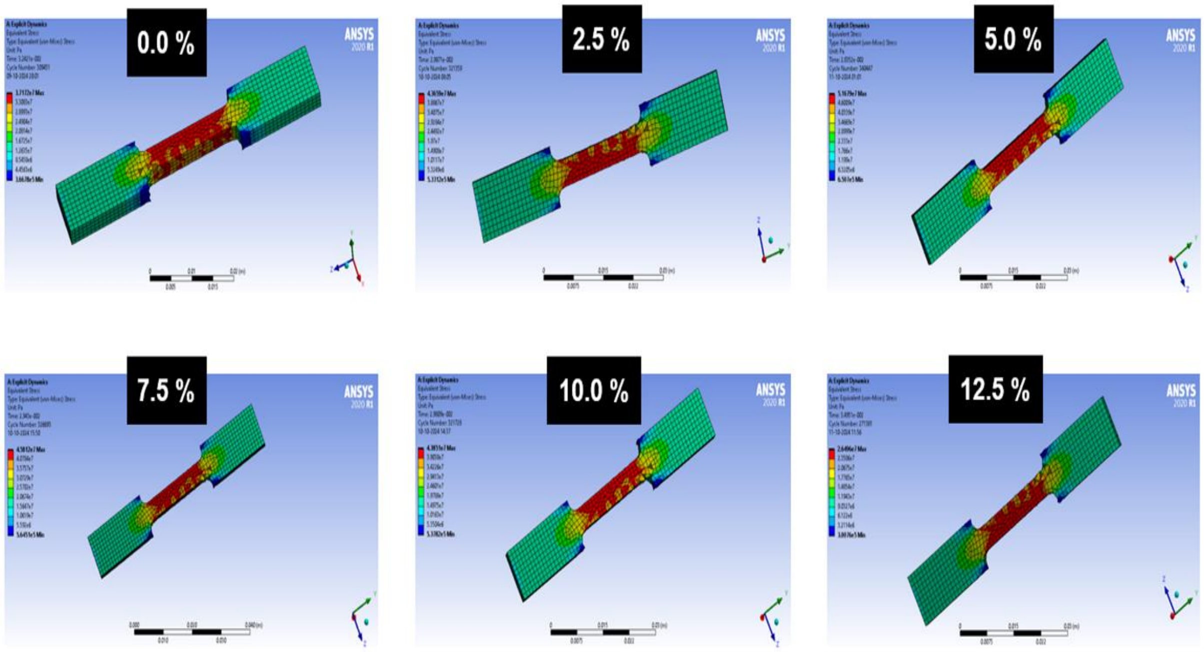

Fig. 2 Analytical results of the modelled parts at different specifications

In this work, the mechanical qualities of a composite substance based on jute that has been thoroughly incorporated and contains variable quantities of filler weight is shown. The experimental evidence demonstrates changes in the tensile properties of the substances with varied proportions of weight. These variances are displayed in Figure 3. The noted disparity could be attributed to modest disparities in input factors, such as boundary circumstances, density, and other characteristics taken into consideration throughout experiment and computational evaluation. According to the information gathered, it is ought to be assumed that incorporating powder particulates boosts the resilience of the composite substance. On the other hand, when the quantity of this particulate in the epoxy increased by in excess of 10 wt. %, this led to a reduction in the rate of stress transfer that occurred beneath the materials, which in turn caused the strength of the composite to decrease [23].

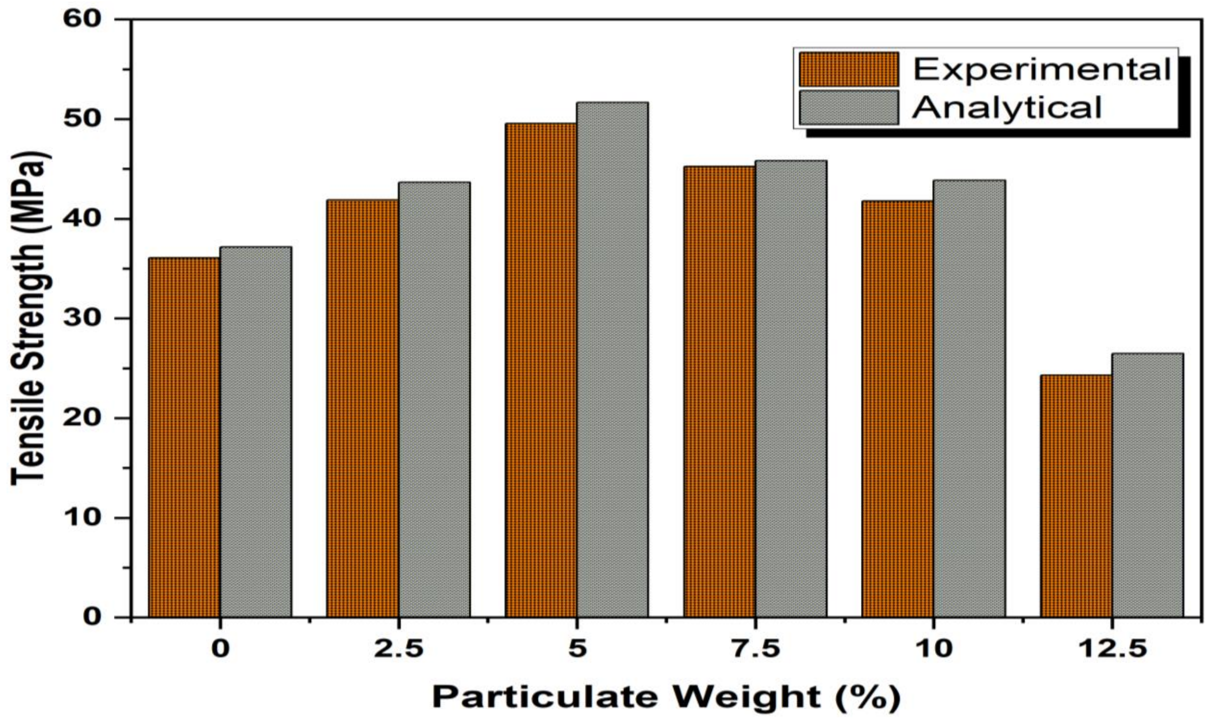

Fig. 3 Comparison of experimental and analytical results for specimens

A curve-fit strategies are implemented for assessing the coefficients for the purpose to build a homogeneous and anisotropic the material. Considering a 5th-order polynomial path, Figure 5 presents a straightforward display of the strength coefficients at various cross-head rates. By studying the above polynomial trajectory, it is obvious that the composite's strength can be estimated by contemplating the fluctuations in particulate proportions and strain rates, although the existence of an enormous disparity in inaccuracy compared to the experimental findings.

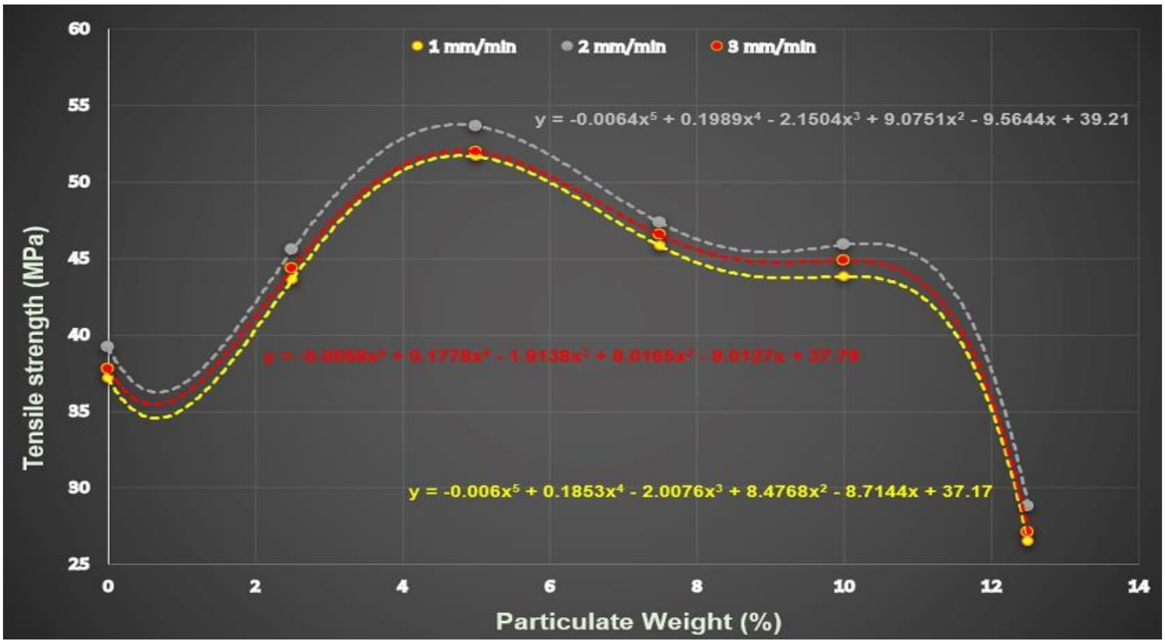

Fig. 4 Curve fitting plot for all analytical results at varied strain rate

IV. CONCLUSIONS

The assessment of the tensile characteristics of JPC was undertaken using FEA technique across certain strain rate, with findings being compared to experimental data. The research generated many major findings:

- The research underlines the rising relevance of NFC, especially those based on jute, due to their lightweight, ecological responsibility, and superior specific mechanical attributes compared to synthetic alternatives.
- Implementing ANSYS R121 for FEA experienced successful in analyzing the tensile attributes of JPC across different particulates proportions (0, 2.5, 5, 7.5, 10, and 12.5 wt.%).
- The computational findings agreed well with actual data, proving the dependability of FEM in predicting mechanical characteristics under given circumstances.
- A fifth-order polynomial model was created to estimate the composite's strength based on particle proportions and strain rates, revealing a mechanism for forecasting performance in practical applications. Also, up to a stain rate of 2 mm/min, the specimen is capable to provide the maximum strength for all considered weight proportions.

So, this technique aid researchers in predicting the mechanical characteristics of NFC using FEA, allowing effective material selection and design for diverse applications.

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