Comparison and Evaluation of physical properties of Short Fiber reinforced composites and Particulate composites

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Abstract

In the current study, samples of natural fibers reinforced hybrid composites were created by hand-laying up, from date palm fiber, sugarcane bagasse, and groundnut shell into an epoxy resin matrix. The prepared samples were tested as per ASTM D3039 (methodology of testing specific to polymer matrix composites). The study revealed that sugarcane bagasse and groundnut shell when used in the particulate form (fine particles) exhibited greater tensile and compressive strengths than when used in short fiber form. It was analyzed that at a maximum force of 889.73N, Tensile stress at maximum force was 5264.70 kPa and tensile strain at maximum force was observed to be 0.32% for short fiber reinforced composites (Specimen 1) whereas for Particulate composites (Specimen 2) at a maximum force of 890.94 N, Tensile stress at maximum force was 5271.85 kPa and tensile strain at maximum force was 0.46%. Also, the compressive stress at maximum force for short fibers was 11699 kPa whereas for particulate fibers was 28246 kPa. It is apparent that morphology of fibers has significant impact on their mechanical properties.

Keywords: *Natural fibers, hand lay-up, morphology, particulate form, mechanical properties;*

1. Introduction

There has been an increase in interest in creating sustainable and eco-friendly products to stop environmental damage and the growing global waste concerns. Researchers and scientists have launched studies on bio-composite materials. India being an agricultural country produces biomass in the form of agro-wastes such as crop residues like sugarcane bagasse, groundnut shell, etc. Amongst the various reinforcement materials/ fillers such as ceramics, fabrics, glasses, metals, natural fibers have been used extensively as reinforcement materials due to their ability to provide strength and stiffness to the matrix. Natural fibers are preferred over synthetic fibers as they are abundantly available, renewable and biodegradable. They exhibit superior mechanical properties such as high tensile strength, high stiffness, good shear properties and high specific modulus. Natural fibers are light in weight and have low density. Due to low coefficient of thermal expansion and high temperature resistance, these fibers can be employed for various heat resistant applications. These are less expensive and provide design flexibility due to which they can be molded into various complex shapes.

Samir Benanibia et.al.[1] prepared composites composed of date palm fibers, cement and sand and assessed the thermal insulation, water absorption as well as mechanical properties of the sample and observed that increasing the weight fraction of date palm fiber reduces the thermal conductivities of the sample. Agro-waste fibers such as sugarcane bagasse and Oil Palm empty fruit bunch fibers have shown enhanced thermal performance, acoustic, physical, and mechanical properties of composites.

Using the fragmentation approach, A.Shalwan et al.[2] looked at the interfacial adhesion of date palm and epoxy fibers. Fibers with smaller diameters have higher interfacial adhesion and an ideal NaOH concentration result in an ideal strength. Additionally, it was discovered that the fragmentation procedure outperformed the single pull-out test.

Hill et al. [3] discussed the history of natural fiber reinforced composites and mentioned the challenges faced by the research community in improving their performance and described some of the chemical modifications and their effect on fiber properties.

According to A.W. Van Vuure et al.'s [4] investigation on the compressive and tensile characteristics of coir fiber, flax, and bamboo, compression is preferable to tension in coir fiber composites.

The impact of oil palm nanofiller on the mechanical and morphological characteristics of kenaf fibers was investigated by N.Saba et al. in 2016 [5]. Hybrid epoxy nanocomposites were created using the wet hand lay-up approach and demonstrated better mechanical and morphological characteristics, making them a viable alternative to traditional building materials.

In order to determine the ideal fiber loading of composites, Mohammad Asim et al. [6] produced composites using date palm fibers (DPF) reinforced phenolic composites by hand lay-up technique by varying DPF ratio and characterised mechanical (tensile, flexural and impact), morphological, and dynamic mechanical properties. The findings made it abundantly evident that 50% DPF composites may be used as insulation for buildings, walls, and false ceilings because they have improved mechanical and thermal characteristics and better interfacial bonding between fibers and matrix.

Due to its excellent qualities, a natural fiber-reinforced bio composite made of kenaf (Hibiscus) fibers mixed with zinc oxide was created by Yingi Wu et al. [7] and assessed to replace commercial car parts.

Based on their sustainability and economic merits, Azizatul Karimah et al. [8] defined the features and main applications of natural fibers. Natural fibres may be used in composites and reinforcing materials because of their low density and high strength. The microstructure and fiber compositions affect the mechanical characteristics. Natural fibers have hydrophilic qualities due to the presence of hemicellulose, which makes them less compatible with matrix materials that have hydrophobic properties. These fibers' cellulose content and crystallinity have a significant impact on their strength. The size and quality of natural fibers are also influenced by other variables, including the environment, the technique of fiber extraction, transportation, storage period, and circumstances.

The use of eco-friendly materials for the creation of composites for a variety of applications has become more popular, according to Mouad Chakkour et al. [9], due to benefits including light weighing and biodegradability, which reduce greenhouse gas emissions. However, there are various issues that may restrict their use because to poor interfacial adhesion, excessive moisture absorption, low processing temperature, and impact strength. Recent research focuses on improving the mechanical characteristics of nano bio-composites made of fillers made of nano-sized clay, crystals, and cellulosic fibers. There are also other approaches of dealing with these materials' issues with fire resistance and moisture absorption.

Using the compression molding process, Mohanavel et al. [10] produced composites of water hyacinth fibers, epoxy resin, and nano-sized tamarind shell ash particles in varied weight percents (0,1,3,5,7,9). The manufactured specimens were evaluated for a variety of mechanical characteristics in accordance with ASTM criteria, and it was discovered that composites containing nano-sized tamarind shell ash particles in the weight percentage of 5% significantly improved their tensile and flexural capabilities. The impact energy and impact strength of composite specimens were similarly decreased by adding tiny, nanoscale tamarind shell ash particles.

The creation of epoxy composites reinforced with banyan fiber and sawdust was the main focus of T. Raja et al.'s study [11]. By altering the proportions of fiber and filler, they created five samples with differing weight ratios, each having a matrix of 60% and 40% reinforcement. They also contrasted the hardness and flexural, tensile, and impact strengths of every created hybrid sample. Investigating surface contact and laminate failure manner was done using SEM analysis.

Using a compression molding process, Razan A.Alshgari et. al. [12] produced hybrid composites of natural fibers with hemp fiber, wood particles, polypropylene, and montmorillonite nano clay. Combining two distinct kinds of natural fibers makes composite materials more durable and environmentally beneficial while also improving their mechanical characteristics. To lessen their hydrophilic characteristics, they also created composites utilizing the alkali-treated hemp and coir fibers. It was discovered that the addition of nanoparticles and fiber mixing increased the mechanical properties of the produced composites. The strongest combinations were hemp, nano clay, 10% weight of each type of wood particle, and 70% polypropylene matrix. The inclusion of nanoparticles considerably improved the fiber's adhesion to and compatibility with the polymer matrices.

2. Materials and experimental procedure

i) Preparation of the mold- Wooden mold of dimension 300 mm x 200 mm x 20 mm was prepared for casting the specimens using hand layup technique.

ii) Selection of the fibers - Three natural fibers selected are midribs of date palm fiber, sugarcane bagasse and groundnut shell due to their abundance in the local areas of Jharkhand and the fact that they contain high cellulose content. The cellulose, hemicellulose and lignin content of the selected natural fibers are mentioned in the table below:

Table 1: cellulose, hemicellulose and lignin content in the fiber

Natural Fibers	**Cellulose**	**Hemicellulose**	**Lignin**
Sugarcane Bagasse	41.8%	28%	21.8%
Date Palm Fiber	44%	26.1%	11.5%
Groundnut shell	44.8%	5.6%	36.1%

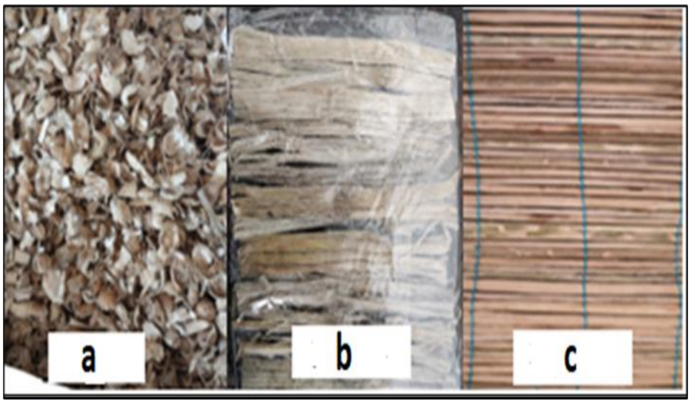

Fig.1. Constituents of Composite a) Groundnut Shell (b) Sugarcane Bagasse and (c) Date Palm fiber

iii) Selection of the Matrix- Thermosets such as EPOXY LY556 and HARDENER HY951 are selected as the matrix material in the ratio of 10:1 as it has great binding properties. The chemical formula of the selected resin and Hardener is shown below.

iv) Characteristics of Epoxy LY556**.**

- It is a clear pale-yellow liquid.
- Viscosity at 250 degrees Celsius- 10000-12000MPa
- Density at 250 degrees Celsius- 1.15- 1.20g/cm^3

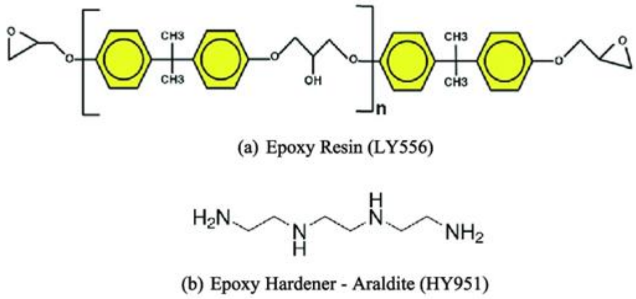

Fig.2. chemical structure of (a) Epoxy resin (b) Hardener

- For resin to form 3-D crosslinked thermoset structure, it must undergo curing reaction with curing agent Hardener tri-ethyl-tetramine HY951 in the ratio of 10:1.

Dimensions of Specimen				
Specimen	**Description**	**Sugarcane Bagasse**	**Date Palm Fiber**	**Groundnut shell**
Specimen 1	Short fiber form	180x1	180x10	30x10
Specimen 2	Particulate form	0.5x0.5	180x5	0.5x0.5
*All dimensions in mm (LxB)				

v) Fabrication of the composites- There are various methods of fabrication of composites such as Hand Lay-up, Compression Molding, Injection Molding, Pultrusion etc. In this investigation, Hand lay-up technique is being employed as it is simple in processing, requires low-cost tooling and the specimens fabricated can be obtained in various shapes and sizes. Natural fibers were soaked overnight in distilled water to remove dust and impurities and then dried in the sun. Fibers were then arranged in short fiber form as well as chopped and grinded in particulate form. Both specimens 1 and 2 have 12% of the weight of the matrix and 88% of the weight of the fibers.

Composition of fibers in the composite was taken as follows:

Date Palm fiber-70%, Sugarcane Bagasse – 15%, groundnut shell- 15%

Table 2: Dimension of the specimen

Fibers were arranged in the mold and Epoxy resin and hardener were gently poured over it. The samples were then compressed with a roller and vacuum bagging was employed to remove air bubbles to avoid creation of voids in the specimens. The fabricated specimens were removed from the mold after a curing time of 48 hours.

Specimen 1

Fig.3. Fabricated Specimen 1 with fibers hybridized a) Front view (b) Back view

Specimen 2

Fig.3. Fabricated Specimen 2: a) Date palm fibers, (b) Particulate form of sugarcane bagasse and groundnut shell and (c) Fabricated specimen with fibers hybridized along with epoxy and hardener

Tensile Test – The specimens of natural fiber composites were prepared as per the dimensions of ASTM D3039. Tensile tests and compressive tests were performed in the Universal Testing Machine (UTM). The tests were carried out on specimens at a gauge length of 165 mm with displacement control at a rate of 1.0 mm/min.

Mechanical performance of the composites- Load-displacement graphs for tensile and compressive tests are plotted for Specimen 1. Stress- Strain curves for tensile tests of the composites are represented in the graphs.

Tensile stress is proportional to the tensile strain (Elastic region) obeying Hooke's law and when stress exceeds the elastic limit, it gets permanently deformed (Plastic region). The curve also shows the region where necking occurs.

From the stress- strain graphs, following parameters can be calculated:

1) Yield Strength: The amount of strength a material can endure before permanently deforming.

2) Ultimate tensile strength. It represents the highest level of strength that a material can bear before failing or breaking.

The graph's Stress coordinate at the location of rupture represents the breaking strength.

3) Young's modulus - According to the "Rule of mixtures," the composite's Young's modulus equals Longitudinal Stress/Strength; $E_c= E_F V_F+E_M V_M$; $V_M +V_F=1$

3. Experimental setup

The universal testing machine model Instron 8801 was used to conduct the tensile and compressive tests in accordance with ASTM D 3039 at room temperature (22 °C), 50% humidity, and a cross-head speed of 1.0 mm/min.

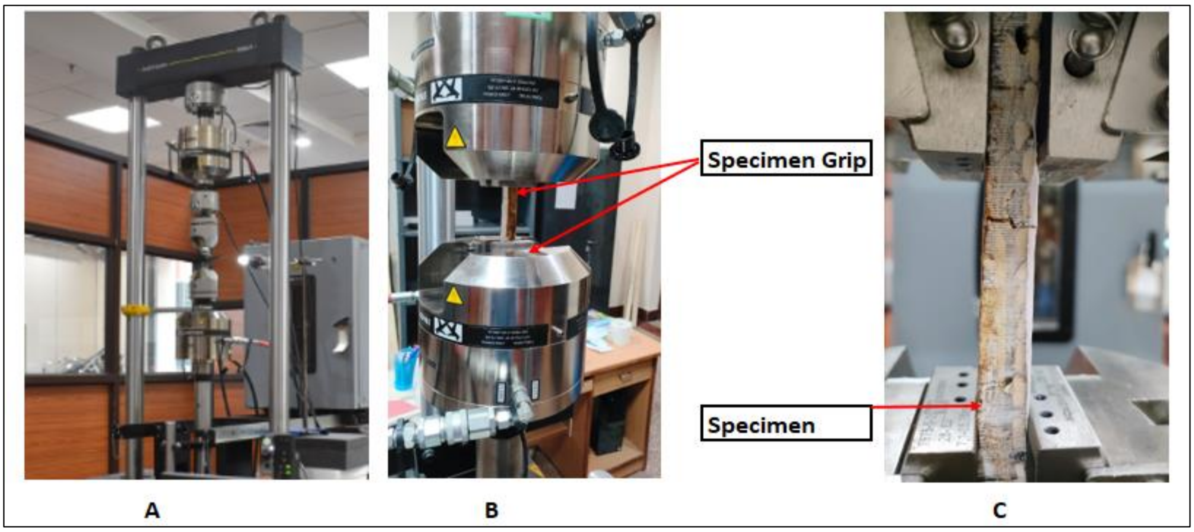

Fig.4. A) Setup of the tensile test according to ASTM D3039: Universal Testing Machine. B) Setup of the tensile test according to ASTM D3039: Specimen grip and Specimen

Fig.5 A) Specimen 1 B) Specimen 2

4. Results and discussions

Experimental Observations for specimen 1 and specimen 2

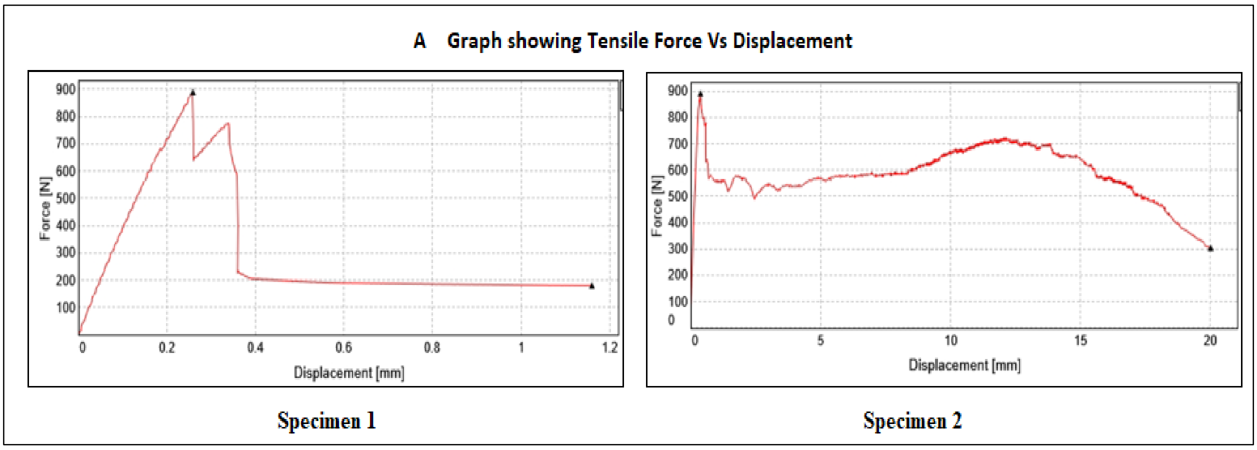

Fig.6. Comparative analysis of tensile force Vs Displacement characteristics of Specimen 1 and 2.

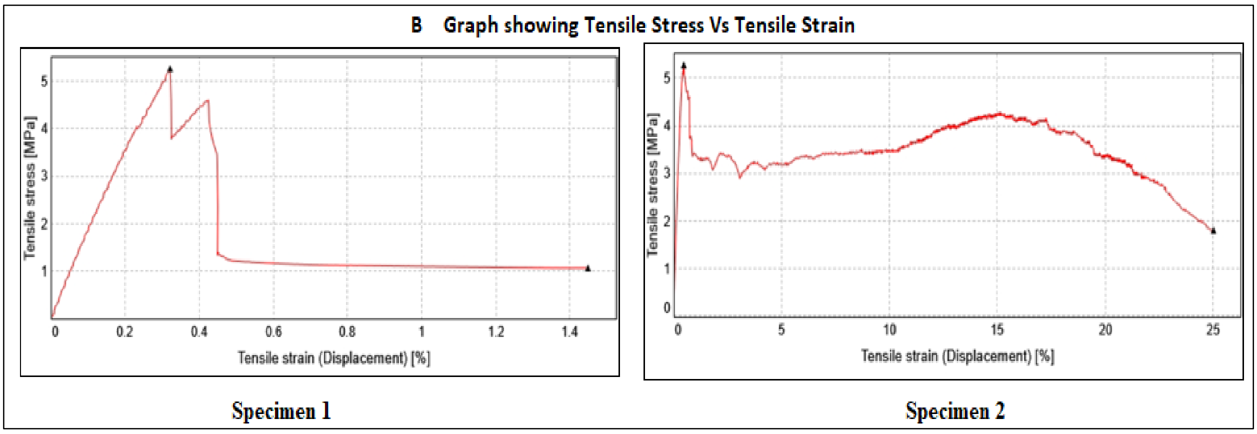

Fig.7. Comparative analysis of Tensile Stress Vs Tensile Strain characteristics of Specimen 1 and 2

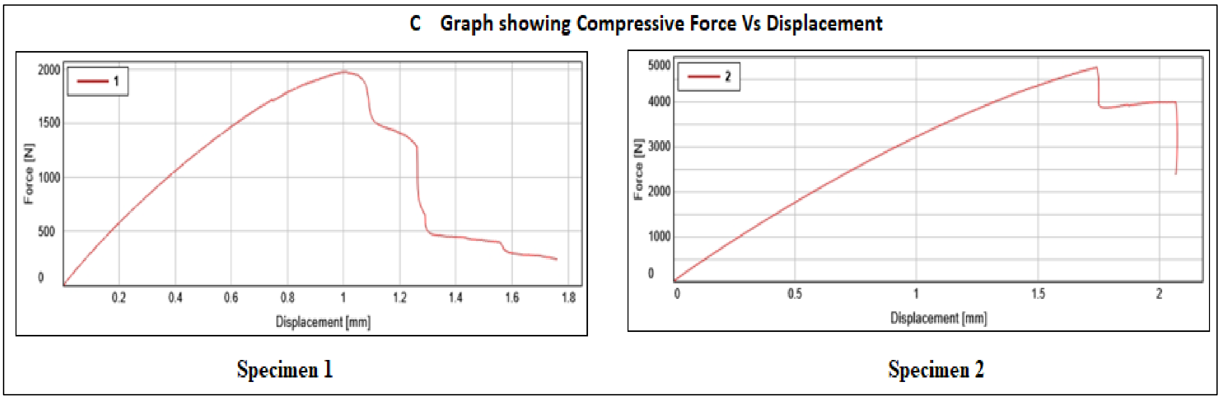

Fig. 8. Comparative analysis of Compressive Force Vs Compressive Displacement characteristics of Specimen 1 and 2

Table 3: Tensile Characteristics of Specimen 1 and Specimen 2

Specimen Label	**Maximum Force [N]**	**Tensile Stress at maximum Force [kPa]**	**Tensile Strain(Displacement) at Maximum Force [%]**	**Tensile Strain (Extension) at Break (Standard) [%]**
Specimen 1	889.73	5264.70	0.32	1.45
Specimen 2	890.94	5271.85	0.46	25.03

Table 4: Compressive Characteristics of Specimen 1 and Specimen 2

Specimen Label	**Displacement at break (Standard) [mm]**	**Compressive Displacement at Break (Standard) [mm]**	**Force at Break (Standard) [mm]**	**Time at Break (Standard) [s]**
Specimen 1	1.76	1.76	245.78	105.46
Specimen 2	2.07	2.07	3998.42	124.09

1) Compared to single fibers, the mechanical characteristics of composites have significantly improved as a result of the hybridization of natural fibers in short fiber and particle form.
2) The tensile strength of short fiber reinforced composites [Specimen 1] show that at a maximum force of 889.73 N, tensile stress at maximum force was found to be 5264.70 kPa and Tensile Strain at maximum force observed was 0.32% whereas for Particulate Composites [Specimen 2] it is found that for a maximum force of 890.94 N, tensile stress at maximum force is 5271.85 kPa and Tensile Strain at maximum force was 0.46%.
3) Tensile strain at break for Particulate Composite has increased drastically to 25% as compared to Short Fiber Reinforced Composite which was 1%.
4) The compressive strength of fibers depicted that for Specimen 1 at a maximum force of 1977.26 N, compressive stress at maximum force is 11699.76 kPa whereas for Specimen 2 at a maximum force of 4773.69 N, compressive stress at a maximum force is 28246.69 kPa.

5. Conclusion

This paper presents the fabrication of hybrid natural fibers reinforced composites using Date palm fiber, sugarcane bagasse and groundnut shell using hand- lay-up technique. Stress- Strain graph of composite materials follows a similar trend as the Stress- Strain graph for other materials such as metals, ceramics and polymers. The hybridized fibers reinforcement in particulate form exhibited better tensile and compressive properties than short fiber form. It has been depicted through the study that morphology of the fibers plays an important role in providing strength to the composite. Other factors such as orientation and alignment of the fibers, different weight ratios of fiber-to – matrix, layering or stacking methods can also be investigated for further studies. Due to numerous advantages, these fiber reinforced composites have potential to be used in various automobile industries, aerospace, interior and exterior parts of infrastructure as well as in the medical fields.

CRediT authorship contribution statement

M.K.Paswan and Ishita Ghosh: Conceptualization. Bipin Kumar Chaurasia: Methodology Supervision, Review & editing. Asma Farheen: Writing – original draft, data acquisition, Investigation. Heman Singh Hansda: Data curation.

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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