Investigating the Mechanical Behaviour Of Jute Fiber, Sisal Fiber, Spider Web, And Chicken Feather Reinforced Hybrid Composite

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***Abstract*: Hybrid composites with their unique properties, can be used in a variety of constructions and/or structural parts without sacrificing their long-term stability and structural performance. Nonetheless, the construction is more cost-effective and environmentally benign when natural fibers are used in composites. This work explores the mechanical characteristics of hybrid composites reinforced with chicken feathers, sisal fiber, jute fiber, and spider web, providing insight into the possible uses of poultry manure in engineering. The need for sustainable alternatives to conventional methods of disposing of chicken waste is essential due to the significant threats they represent to the environment and human health. Experiments revealed that introducing more chicken feathers increases the composite's tensile strength, but it may also decrease its flexural strength and hardness because of adhesive limits and air bubbles. However, the mechanical properties of the composite materials show promise, making them attractive choices for engineering applications. Their increased performance over substitute materials highlights their promise in a variety of industries where strength, resilience to bending forces, durability, and resistance to impact are critical. Significant cost savings and the reduction of environmental and health risks related to traditional disposal techniques can be achieved by using poultry waste in composite production processes. This study also establishes the foundation for future research, paving the way for a more sustainable and environmentally friendly future.**

Keywords: Hybrid composites, Poultry waste utilization, Mechanical behavior, Eco-friendly materials, Engineering applications, Ecological concerns

I. INTRODUCTION

Composite materials have garnered significant attention in various engineering fields due to their exceptional properties and versatility [1-3]. Composites are useful for a wide range of applications because they may be designed to exhibit desired qualities by combining different ingredients, such as fibers and matrices [4–7]. Because of their abundance, affordability, and environmental friendliness, natural fibers—among the many varieties of fibers utilized in the production of composites—have shown great promise as synthetic counterparts [8–10]. Lately, scientists have started investigating new mixes of natural fibers to create hybrid composites with improved mechanical qualities. Natural materials such as jute, sisal, spider web silk, and chicken feathers have garnered attention due to their distinct qualities and possible uses in the production of composite materials. Since each of these fibers has unique mechanical and structural characteristics, they are all excellent choices for reinforcement in composite materials.

The Corchorus plant yields jute fiber, which is well-known for its great tensile strength, low density, and biodegradability [11–14]. The fiber known as sisal, which is derived from the Agave sisalana plant, is very resistant to abrasion and can absorb moisture [15–18]. Produced by a variety of spider species, spider web silk is stronger, more elastic, and more durable than many synthetic fibers [19–21]. Poultry feathers are the source of chicken feather fiber, which provides a low-cost, lightweight substitute with special thermal insulation qualities [22–25]. Researchers intend to harness the strengths and synergistic benefits of these various natural fibers to generate materials with improved mechanical performance by mixing them in hybrid composites. Understanding these hybrid composites' potential uses in the construction, automotive, aerospace, and textile industries depends on an examination of their mechanical behavior.

The goal of this study is to investigate the mechanical properties of hybrid composites reinforced with chicken feathers, sisal, jute, and spider web silk. The purpose of extensive testing and analysis is to clarify the impact of fiber composition, orientation, and hybridization on the overall mechanical properties of the composites. This includes tensile, flexural, impact, and fracture toughness tests. In addition, the study will examine the composites' microstructural features to clarify the mechanisms influencing their mechanical properties. The results of this study have important ramifications for the creation of high-performing, environmentally friendly composite materials with a wide range of industrial uses. This work advances the continuous search in material science and engineering for effective and environmentally friendly substitutes by utilizing the special qualities of natural fibers and investigating novel hybridization techniques.

II. LITERATURE REVIEW

Lalhminghlui et al., 2021 [26] investigated the mechanical properties of hybrid composites reinforced with bamboo fibers and chicken feathers at various weight fractions. The fabrication of these composites has been achieved through the hand layup method, and subsequent mechanical property tests, including tensile and flexural strength, were conducted using the FIE Electronic Universal Testing Machine. Prasanth et al., 2021 [27] focused on utilizing chicken feather fibers, a poultry waste, in epoxy resin composites. Through the hand layup method, chicken feather fiber-reinforced composites were produced with three different fiber reinforcement loadings. Various experimental investigations have been carried out to evaluate the mechanical properties of the composites, providing insights into the potential applications of chicken feather fibers. Regassa et al, 2021 [28] investigated the burst strength of a spider web-formed fabric structure created using an Embroidery machine. The self-stressing nature of the spider web structure has been explored, suggesting its potential as a fiber orientation technique for enhanced composite reinforcement. The study has emphasized the influence of fiber orientation on the mechanical properties of fiber-reinforced composites and highlighted the spider web form as a promising candidate for future engineering composite products.

Franz et al., 2022 [29] explored a novel approach for load introduction in sandwich structures using spider web-inspired structures made of fiber-reinforced plastic materials. Comparative studies between spider web structures and conventional load introductions have been conducted to assess the potential improvements in load distribution and lightweight design. Farzana et al, 2022 [30] provided an overview of jute fiber-reinforced polymer composites, emphasizing the advantages of jute, such as low processing cost, low density, stiffness, and excellent mechanical properties. The paper covered various types of jute composites, including those involving thermoset and thermoplastic polymers, bio-based resins, and hybrid composites, along with their mechanical characterizations and applications in construction, automotive, and aerospace. Zakaria et al., 2018 [31] conducted an experimental investigation on the flexural, compressive, and tensile strengths of Jute Fiber Reinforced Concrete Composites (JFRCC) and Jute Yarn Reinforced Concrete Composites (JYRCC). The study has involved different mix ratios of concrete and varied cut lengths of jute fiber and yarn. The findings indicated a significant increment in strength, particularly for JYRCC, suggesting that the presence of jute yarn and higher cement content contributed to enhanced concrete strength.

III. PROPOSED METHODOLOGY

3.1 Materials and Methods

The work focuses on the careful production of hybrid composites using a prudent selection of reinforcement materials—jute fiber, sisal fiber, spider web, and chicken feathers—that have been selected based on their excellent mechanical properties. The intrinsic mechanical qualities and environmental sustainability of these natural fibers led to their selection. To further improve the composite's structural integrity and durability, HY951 hardener was added to the mixture. A strong and uniform composite material was produced as a result of the reinforcing fibers being more easily consolidated inside the resin matrix through the application of compression molding. This method made sure that the various fibers were successfully integrated, each of which added a special quality to the finished composite. Utilizing rigorous material selection and processing methods, the composite was optimized to demonstrate exceptional mechanical properties and appropriateness for engineering uses. Figure 1 shows the image of the hybrid composite.

Figure 1: Hybrid Composite

3.2 Manufacturing of the Composite

The hand layup technique (Figure 2) was used in the production of the composite specimens. Wax was first applied to the mold to make the specimen removal process easier. The mold cavity was then filled with pineapple leaf fibers, and a measured amount of resin with hardener was poured in. After closing the mold box and adding enough weight to it, it was heated for an hour at 90°C. After allowing the mold box to cool, the specimens were created. These samples were tested, and the results were tabulated. Specimens with volume ratios of 10%, 20%, and 30% were tested for hardness. Remarkably, the specimen with a 10% volume ratio had a hardness of 40B, but the specimen with a 20% volume ratio had a hardness of 59 B. The specimen with a 30% volume ratio had the maximum hardness, measuring 84B. This suggests that hardness rose by up to 30% as the volume ratio increased.

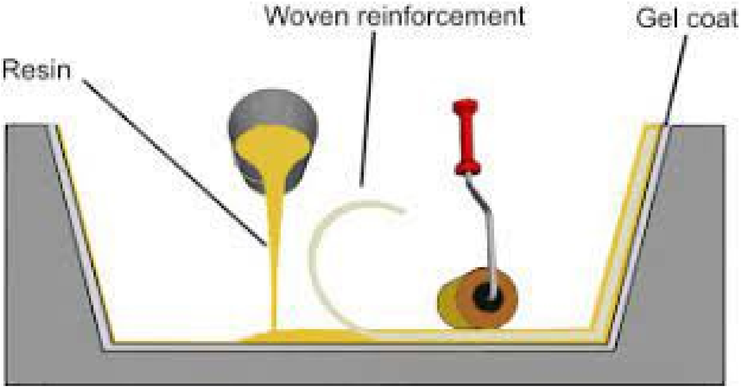

Figure 2: Hand Lay-Up Technique

Fiberglass—also referred to as fiberglass—is a common kind of glass fiber-reinforced plastic. The strands can be woven into a fabric, flattened into a sheet (chopped strand mat), or arranged randomly. Usually based on materials like epoxy, polyester resin, vinyl ester, or thermoplastic, the plastic matrix is a thermoset polymer. Fiberglass is more affordable and flexible than carbon fiber, but it is nonetheless stronger in weight than many metals. It can be shaped into intricate shapes, is transparent to electromagnetic radiation, non-magnetic, non-conductive, and chemically inert under most conditions. Roofing, pipes, cladding, orthopedic casts, surfboards, cars, boats, bathtubs, enclosures, swimming pools, hot tubs, septic tanks, and water tanks are just a few of the industries in which it finds use. Instead of only referring to the glass fiber itself, this article follows the norm that "fiberglass" refers to the entire glass fiber reinforced composite material.

3.3 Mechanical testing

By ASTM guidelines, fiber-reinforced composite specimens were made and subjected to three mechanical tests: the impact, flexural, and tensile tests. The following are the specimen dimensions and shapes for the respective tests:

3.3.1 Tensile Test

The tensile test, sometimes referred to as the tension test, is a mechanical test used to evaluate the strength, ductility, elasticity, and plasticity of materials. Researchers can examine a specimen's behavior under tension by subjecting it to an increasing tensile force until it fails. For composite materials, tensile testing is an essential process to evaluate their mechanical characteristics under tension. This test helps in understanding how materials behave when subjected to stretching forces, aiding in material selection, quality control, and design optimization. The tensile stress (σ) is calculated using the formula:

$$\sigma = F/A \qquad (1)$$

Where," σ = Tensile stress (MPa), F = Force applied (N), and A = Cross-sectional area of the specimen (mm²)". An Xforce HP load cell and a Zwicki machine with a Z2.5kN capacity are used to perform the tensile test on composite materials. The test starts with an applied pre-load of 0.1 MPa. The test starts at a grip-to-grip separation of 89.00 mm and moves forward at a pace of 50 mm/min. Tensile modulus is calculated at a rate of one millimeter per minute, and Method B is utilized to estimate nominal strain. The precision control and measurement provided by this configuration allow for an accurate evaluation of the mechanical properties of the composite materials under tension.

3.3.2 Flexural test

The bending modulus, sometimes referred to as the modulus of elasticity in bending or flexural modulus, quantifies the resistance of a material to deformation when subjected to bending force. Within the proportional limit of the material, it is defined as the ratio of stress to strain. In contrast, a material's flexural strength indicates the highest stress it can bear before breaking during bending. The flexural modulus (E_f) can be calculated using the formula:

$$E_f = \frac{F.L^3}{4bh^3d} \qquad (2)$$

Where: "E_f = Flexural modulus (in MPa), F = Applied force (in N), L = Span length between supports (in mm), b = Width of the specimen (in mm), h = Thickness of the specimen (in mm), and d = Deflection (in mm)". According to DIN EN ISO 178, the Flexure Test is an essential technique for evaluating the bending characteristics of composite materials. Specimens are taken out by hand and prepared for this test without any prior care. To ensure accurate testing, the Z2.5 Kn Flexure Kit is used, which offers consistent conditions. Before the flexural test, the specimens are subjected to a pre-load of 0.1 MPa. Greater stiffness is indicated by a higher flexural modulus, while stronger resistance to bending is indicated by a higher flexural strength.

The Charpy Impact Test is a standardized procedure used to calculate the energy a material absorbs during fracture. A material's toughness is evaluated by subjecting it to a sudden impact in a controlled environment. For a variety of technical applications, this test is especially vital for determining a material's capacity to tolerate abrupt shocks or impacts. The Charpy Impact energy (Joules) absorbed by the specimen is calculated using the formula:

$$E = \frac{mgh}{1-A} \qquad (3)$$

Where, "E = Impact energy (Joules), m = Mass of the hammer (kg), g = Acceleration due to gravity (m/s^2), h = Height of the fall (m), and A = Fraction of the energy absorbed by the striker". Specimens are prepared for this test following ISO 179-1 requirements and conditioned suitably for testing. With its 2.7J hammer, the HIT 5.5p machine produces dependable and consistent output. Greater toughness, indicated by higher absorbed energy, makes the material more appropriate for demanding applications.

IV. RESULTS AND DISCUSSION

4.1 Impact Test

Sl. No.	Theoretical Impact Velocity (m/s)	Angle of Release (°)	Total Mass (kg)	Work Capacity (J)	b (mm)	h (mm)	W (j)	Ak (KJ/m^2)	Type of failure	The angle of rise (°)	AK-series
1	3.458	148	0.4515	2.70	12.7	7.167	2.30443	25.32	P	42.75	20.12C (P)
2	3.458	148	0.4515	2.70	12.7	7.167	2.54124	27.92	H	26.37	
3	3.458	148	0.4515	2.70	12.7	7.167	1.12161	12.32	C	94.23	

Table 1: Charpy Impact Test on Composite

3.3.3 Impact test

The Charpy Impact Test on Composite data, which offers important insights into how the tested materials behave under impact, is shown in Table 1 and Figure 3. With a total mass of 0.4515 kg, each specimen was released at an angle of 148 degrees and exposed to a constant theoretical impact velocity of 3.458 m/s. All specimens had the same Work Capacity, or the energy absorbed during fracture, which was 2.70 J. This shows how well the materials can absorb energy in the event of an impact. The specimens were uniform in testing settings because they had the same breadth (b) and thickness (h), measuring 12.7 mm and 7.167 mm, respectively. Additional examination of the specific energy absorption per unit area (Ak) yields information about each specimen's impact strength. The Ak value of specimen 1 was found to be 25.32 KJ/m2, whereas specimens 2 and 3 showed corresponding Ak values of 27.92 KJ/m2 and 12.32 KJ/m2. These figures aid in determining the materials' resistance to impact forces normalized by the area of the specimen. Further insight into material behavior can be gained from the type of failure that was seen during testing. A partial failure (P) was observed in Specimen 1, indicating a degree of deformation or cracking. A hard failure (H) occurred in Specimen 2, indicating a more abrupt and serious fracture. Specimen 3 on the other hand showed a complete failure (C), indicating a total fracture. Information on the deformation properties of the materials under impact is obtained from the corresponding angle of rise during fracture. The angles of rise for specimens 2 and 3 were 26.37 degrees and 94.23 degrees, respectively, while specimen 1 showed an angle of rise of 42.75 degrees.

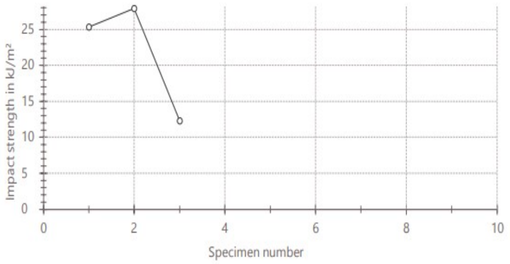

Figure 3: Graph on Charpy Impact test On Composite

4.2 Flexure Test

Sl. No.	E_f (MPa)	σ_{fc} (MPa)	σ_{fM} (MPa)	S_{fM} (%)	σ_{fB} (MPa)	S_{fB} (%)	Lv (mm)	h (mm)	b (mm)
1	537	-	29.5	3.8	29.5	3.8	64	10.6	11.5

Table 2: Flexure test on composite Material

The data gathered from performing flexure tests on composite materials is shown in Table 2 and Figure 4. The specimen exhibits a 537 MPa flexural modulus (E_f). The highest stress that the material sustained at the outermost fibers before failure is represented by flexural strength (σ_{fM}), which is 29.5 MPa in this case. In a similar vein, the bending strength (σ_{fB}), which may take into account more than just the outermost fibers, is likewise 29.5 MPa. The amount of deformation the material experiences at the site of greatest tension during flexure and bending, respectively, is indicated by the flexural and bending strain at maximum load. In this instance, 3.8% is recorded for both. The dimensions of each specimen—"the span length between supports (Lv), thickness (h), and breadth (b)"—are also listed in the table. These dimensions are essential for the setup and analysis of the test. For instance, the specimen with Serial Number 1 has dimensions of 64 mm for span length, 10.6 mm for thickness, and 11.5 mm for width.

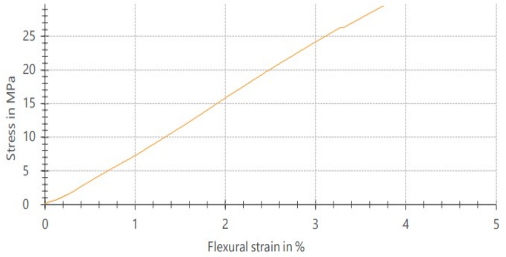

Figure 4: Graph on Flexure test on Composite Material

4.3 Tensile Test

Sl. No	Curve	E_t	Yield Stress (MPa)	Yield strain (%)	σ_m (N)	Max Load (MPa)	S_m (%)	Stress at Bread (MPa)	Strain at Break (%)	S_{tb} (mm)	b (mm)	h (mm)
1	Type 3	13.8	7.89	12	999	7.89	12	1.58	-	30	12.6	10.05
2	Type 1	20.5	-	-	1040	7.76	5.9	7.76	5.9	-	12.7	10.50
3	Type 1	14.4	-	-	857	5.98	8.1	5.98	8.1	-	13.52	10.60
4	Type 1	10.2	-	-	1160	6.80	8.7	6.80	8.7	-	13.95	12.24
5	Type 1	18.4	-	-	679	5.39	6.5	5.39	6.5	-	11.44	11.02

Table 3: Tensile Test on Composite Material

The tensile test results for composite materials, which are shown in Table 3 and Figure 5, provide important information about their mechanical characteristics and behavior. The investigated composite materials show a range of tensile moduli (E_t) from 10.2 MPa to 20.5 MPa. Higher numbers imply stronger resistance to deformation under tension. This shows variations in stiffness among the materials tested. The commencement of plastic deformation is shown by yield stress and yield strain, which demonstrate the materials' capacity to bear loads before permanent deformation takes place. The yield stress levels and yield strain percentages range from 12 MPa to 18.4 MPa and 5.9% to 8.7%, respectively, according to the data. These variations demonstrate how the strength and ductility of the materials differ. The maximum load (σ_m) is the highest load that the materials can support before failing. The materials' load-bearing capacity are shown by values between 679 and 1160 N; larger numbers correspond to greater strength. The stress at break sheds light on the fracture behavior of the material. The values show the stress levels at which the materials fracture and vary from 5.39 MPa to 7.89 MPa. The strain at break serves as a gauge for the degree of material deformation that occurs before fracture Further information on the specimens' dimensions at the fracture point is provided by the thickness (S_{tb}), breadth (b), and height (h) measurements, which helps to clarify the structural characteristics of the materials.

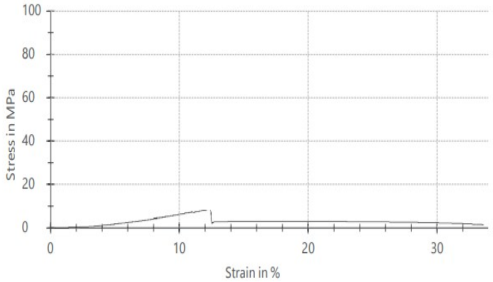

Figure 5: Tensile Test on Composite Material

4.4 Overall Result

Promising results were obtained from the extensive testing that was carried out on the composite materials using Zwick Roell equipment. The composite materials were shown to be superior in several areas when compared to materials such as GFRP and pure Jute fiber. In tests involving impact, flexure, and tensile strength, the composite materials continuously demonstrated excellent mechanical qualities. The materials' exceptional energy-absorbing capacity in the impact test was shown by the specimens' constant Work Capacity values. Furthermore, the examination of individual energy absorption per unit area demonstrated their resistance to impact forces that are normalized by area. A significant flexural modulus, which indicates stiffness under bending force, was demonstrated by the composite materials during flexure testing. Furthermore, the material exhibited noteworthy bending and flexural strengths, indicating its ability to bear external stresses until failure. The materials displayed different tensile moduli throughout the tensile test, which suggests that their stiffness levels varied. A high maximum load value indicated exceptional load-bearing capabilities, and yield stress and strain values indicated its capacity to tolerate loads before permanent deformation occurred. Their fracture behavior was revealed by stress at break, and their deformation properties were explained by strain at break.

V. CONCLUSION

In conclusion, the investigation into the mechanical behavior of jute fiber, sisal fiber, spider web, and chicken feather reinforced hybrid composite sheds light on the potential of utilizing poultry waste in engineering applications. Poultry waste disposal techniques that rely on traditional methods provide a substantial danger to the environment and human health, making sustainable solutions desperately needed. Because of inadequate adhesiveness and air bubbles in the composite, the study shows that while adding more chicken feathers to the composite increases its tensile strength, it can also cause a drop in its flexural strength and hardness. These difficulties notwithstanding, the composite materials show encouraging mechanical characteristics that make them attractive choices for engineering uses. Their advantages over alternative materials highlight their potential applications in a wide range of industries where strength, resilience to bending forces, and durability are critical factors. Poultry waste can be used to make composite materials, which not only reduces costs significantly but also helps to address environmental and health issues related to conventional disposal techniques. To contribute a greener and more sustainable future, this research paves the path for future development and use of sustainable materials in engineering applications.

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