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Design and Development of Fiber Sandwiched Composite Materials for the Improvement of Mechanical Properties

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Abstract

This research paper presents the development and mechanical characterization of fiber sandwiched composite materials (FSCM) to address the increasing demand for high-strength, lightweight, and corrosion-resistant materials in advanced engineering sectors such as automotive, aerospace, and transportation industries. Traditional homogeneous materials such as metals, ceramics, and polymers often fail to provide a balanced combination of properties like high tensile strength, low density, toughness, abrasion resistance, and impact resistance needed for modern structural applications. In contrast, composite materials, which consist of a reinforcement phase (fibers/particles/flakes) and a continuous matrix phase, offer superior performance through enhanced strength-to-weight ratio and customizable properties. In this study, laminated sandwich composite specimens are fabricated using teakwood as the core material, reinforced with different fiber laminae, including carbon fiber, aramid fiber, jute fiber, and banana fiber. All fiber orientations are maintained at 0° to achieve uniform structural behavior and to simplify comparative evaluation. The FSCM samples are manufactured by adopting the hand lay-up technique, which is cost-effective and suitable for experimental as well as small-scale industrial production. The fabricated composites are experimentally evaluated for key mechanical properties such as tensile strength, bending strength, and impact strength, following standard American Society for Testing and Materials (ASTM) testing procedures. Additionally, the experimental results are supported and validated through finite element analysis (FEA) to improve the reliability of the findings. The main objective of this research paper is to compare the performance of different fiber-reinforced sandwich combinations and to identify the optimum material configuration that provides improved mechanical strength with reduced weight, making it suitable for practical structural applications.

Keywords: Composite materials, fiber-reinforced polymer, Fiber composites, finite element analysis, glass fiber-reinforced polymer

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INTRODUCTION

Modern trends in engineering applications require materials with unusual physical and mechanical properties that may not be met by individual conventional homogeneous metals, ceramics, or even polymers. For example, materials are required for underwater, transportation, and aerospace applications. Research and development teams working in large-scale industries, such as the aerospace industry, always research and develop structural materials that have high-strength, low density, good toughness, corrosion resistance, impact resistance, and abrasion resistance. Generally, strong materials have higher densities; if the process is performed to increase the strength of a particular material, it generally leads to a decrease in impact strength. So, the composites are wholly greater than the sum of the parts of materials [1].

The use of composite materials, such as fiber-reinforced polymer (FRP), carbon fiber-reinforced polymer (CFRP), and glass fiber-reinforced polymer (GFRP), is increasing rapidly in industry. This is because of the characteristics of these materials, including high-strength, low cost, and minimum weight. In the aerospace industry, these materials have been most useful in the last 30 years. Composite materials, in combination with different materials, help to achieve the desired properties [2]. In general, these materials have replaced sheet metal in many automobile industries. Each type of composite material has its own properties and can be easily changed or adapted by changing either the percentage of content or the content itself. A composite is a combination of two constituents: reinforcing (in the form of a sheet or fiber) and matrix (in the form of a continuous structure). Sandwich materials have more strength and are widely used in aircraft, satellites, automobiles, transportation, and many polymer industries [3].

A composite material (CM) is a structural material fabricated by combining two or more materials that are insoluble with each other at the macroscopic level (Figure 1) to develop the desired physical and mechanical properties. One material is known as the reinforcing material, and the other is known as the matrix. Reinforcing materials can be fabricated in the form of fibers and flakes [4].

Examples of such composite materials are reinforced concrete, CFRP, and GFRP. Bamboo and corn fibers are also examples of natural composites (NC), in which one of the two materials is naturally occurring and is combined to reinforce and bind together [4].

Carbon fiber tubes (Figure 2) made from carbon fibers are one application of composite materials. All composites usually have the same parts, involving a matrix or binder and reinforcing material. CFRP is a common type of composite material [3].

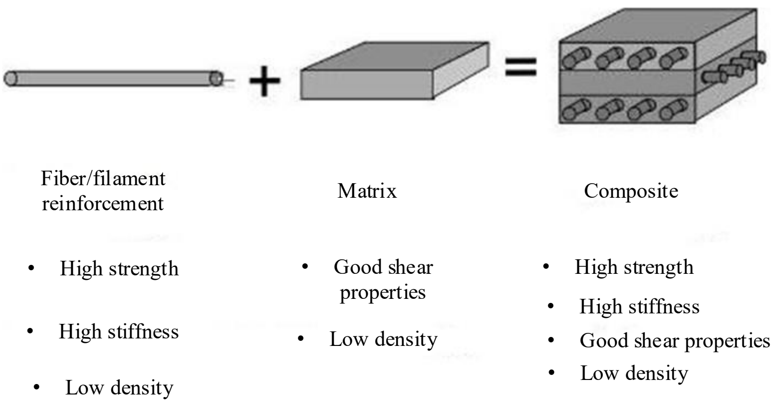

Figure 1. A composite material [4].

Figure 2. Carbon fiber tubes [3].

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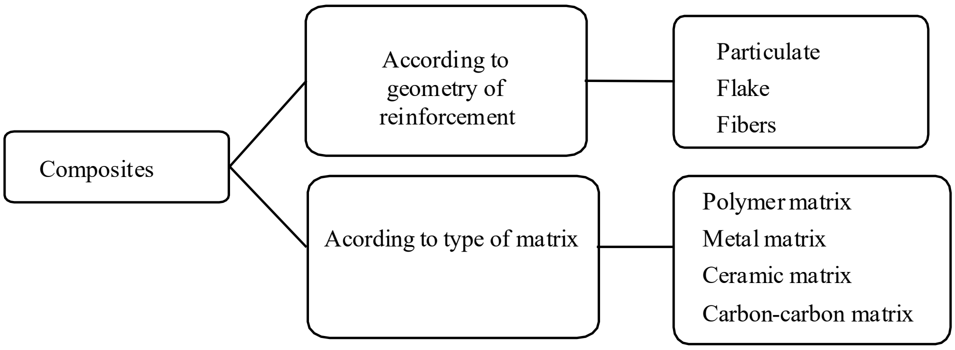

Figure 3. Classification of composites [3].

Classification of Composites

The composites are classified as shown in Figure 3.

Carbon fibers reinforced in a matrix material involving metals and non-metals are combined to form it. Reinforced concrete is another well-known example of a composite material. The reinforcement of concrete uses concrete as the matrix and rebar as the fiber, which improves the strength of reinforced concrete. Composite materials are used in automobiles to improve fuel efficiency by decreasing the overall weight of the vehicle, to improve the aesthetic design and component consolidation, to provide a sleek aerodynamic design, and to improve safety and crash issues [5].

According to the Geometry of Reinforcement

Particulate Composite

Particulate composites are fabricated by immersing particles in matrices of alloys and ceramics. These particles are added randomly; therefore, the particulate composite is isotropic in nature. These composites exhibit improved strength and good oxidation resistance properties. For example, metal particles are added to rubber, such as aluminum in rubber composites [1, 3].

Flake Composite

Flake composites combine flat reinforcements of matrices. Flat matrices improve the high bending strength and are available at a low cost. For example, glass and mica can be used.

Fibers Composites

Fiber composites include short and long fibers, such as carbon and aramid, and matrix materials, such as epoxy resins and aluminum laminae. These fibers are usually anisotropic or assumed to be orthotropic for mathematical analysis. The fundamental unit of such composites is a unidirectional lamina fabricated from these fibers. The lamina is one layer of unidirectional fibers, and a laminate can be formed by combining different layers of such unidirectional laminae [1, 3].

According to the Type of Matrix

Polymer Matrix Composite

These are the most general composites, known as polymer matrix composites (PMCs). They consist of polymer (epoxy, polyurethane) as a matrix material and thin-diameter fibers such as graphite, boron, etc. They are at a low cost, high-strength, and easily manufactured. The strength of graphite epoxy composite is five times more compared to steel material. The main limitations on the use of these materials are low operating temperatures and high coefficients of thermal expansion. The low operating temperature affects the properties of the PMCs highly [1, 3].

Metal Matrix Composite

As the name implies, metal matrix composites (MMCs) include metals such as aluminum and titanium as matrix materials. The fiber materials include carbon and silicon carbide. Metals are generally reinforced to add or reduce properties for suitability in the design. A typical example of such reinforcement is that metal matrix improves stiffness and strength, and fibers reduce the thermal and electrical properties. MMCs are generally applied to provide benefits over traditional metals, such as steel and aluminum. The elastic properties and specific strength and modulus improve with the application of these MMCs [1, 3].

Ceramic Matrix Composite

Ceramic matrix composite (CMC) has a ceramic matrix such as silicates of Calcium and aluminum, and reinforcement by the fibers of carbon and silicon carbides. The excellent characteristics of such MMCs include high-strength, good hardness, higher service temperature limits, low density, and good chemical properties. They have a low toughness value. They fail catastrophically under tensile or impact loading. The volume fraction of carbon fibers improves the properties of CMCs. In applications where high mechanical strength and more service temperatures are desired, the CMCs are the first preference to apply. They are used to manufacture high-strength tool inserts and for future aerospace applications [1, 3].

Carbon-Carbon Matrix Composites

The name implies that the composites made by the combination of carbon fibers reinforced in a carbon matrix are called carbon-carbon matrix composites. These materials are applicable in high-temperature environments, usually of about 3,000 degrees Celsius. The strength of such Carbon–Carbon Composite (CCC) is 20 times higher and 30% lighter than that of graphite fibers. Carbon is generally a brittle material. The reinforcement of the carbon matrix permits the failure of carbon in a gradual manner. They have good properties, including high-temperature service, good mechanical properties of tension and impact, low creep, and low tensile strength. The main limitations of these materials are high manufacturing costs and low shear properties [1, 3].

LITERATURE SURVEY

The Mesopotamians are known to be the first people to have glued wood strips at convenient angles to create ply in 3400 BC. Subsequently, the Egyptians used layers of linen in plaster to make masks. In the early 1500 BC, builders of these people used straw to reinforce bricks and boats. The Ten Books on Architecture described the cement in 25 BC, which is similar to Portland cement used today [6].

Thus, builders and artisans have maintained an interest in composite materials from ancient times. Around 1200 AD, the Mongols invented primary composite bows by combining wood, bamboo, silk, and bones. These high-strength bows ran the era to 1800.

Around the 1870s, chemical development was going quickly, and there was the development of new, stronger resins that formed solids by the polymerization method. Early synthetic resins included melamine and Bakelite [6].

In the 1900s, chemical advances led to the development of plastics. Materials such as vinyl, polystyrene, phenolic, and polyester were invented, and reinforcement was provided to improve strength and rigidity. The composites used today were the result of rapid developments in the 1930s. Owens Corning [6] introduced glass fiber and fiber-reinforced materials for industry. In 1936, high-performance epoxies were developed to meet the demands of industries.

The demand for high-class materials during World War II impacted the FRP industry from research to production. Owing to its high strength-to-weight ratio, chemists were interested in designing FRP materials for electronic equipment and boat parts. The first commercial FRP boat was invented during this era. Around 1947, a fully developed automobile made of FRP composites was invented and tested. Fiberglass preforms impregnated with resin were molded in this car. Innovations in pultrusion, vacuum bagging (VB), and filament winding (FW) were developed in 1950. The concept of filament winding is a typical example of the composite materials used in the aerospace industry [6].

In the late 1960s, carbon fiber was patented and used in the early years for production. Carbon fiber has been developed and used in thermostats and other electronic components. Currently, the marine market is the largest consumer of composite materials. The automobile market has suppressed the marine market in the development of fiber composite materials.

Studies on Natural Fibers

Studies on Jute Fibers

Singha et al. [7] described that during the most recent couple of years, natural fibers have received significantly more attention than any time in recent memory from the examination community. These natural fibers offer various benefits over conventional synthetic fibers. In the current study, an investigation on the synthesis and mechanical properties of a new series of green composites, including *Hibiscus sabdariffa* fiber as a building block material in urea–formaldehyde (UF) resin-based polymer matrix composite, is reported. The static mechanical properties of arbitrarily oriented personally blended *Hibiscus sabdariffa* fiber-supported polymer composites, for example, tensile, compressive, and wear properties, were explored as a component of fiber stacking. The significance of static mechanical analysis (SMA) as a tool in the investigation of the conduct of polymer bio-composites is of central significance.

EXPERIMENTATION

Tensile Test

A tensile test was performed to evaluate the effect of shearing forces applied to the samples and subjected to twisting couples. This is the most widely used test in mechanical testing. This test helps to obtain the mechanical tensile properties, including elastic limit, yield point, breaking point, and constants, such as Young's modulus and Poisson's ratio. In the tensile test, an axial load was applied to a circular cross-section bar or a flat rectangular cross-section sample. Typical sample sizes specified by ISO or ASTM standards are helpful in obtaining accurate results for the tensile test.

One end of the sample is fixed on the frame (adjustable cross head), and the other end is fixed on the movable cross head (tension head) by clamps. A constantly increasing load is applied to the sample by the hydraulic system. The upward movement of the tension head increases the length of the sample; that is, the sample elongates. The tensile test is based on the principle that deformation is a function of the applied load. The load–displacement curve can be obtained using a computerized system, and an extensometer is used to calculate the applied load. The magnitude of the load and displacement is measured at intervals by a computer. Once the curve between the load and displacement is obtained, stress and strain are evaluated based on the curve. Other properties, such as yielding, ultimate, and breaking stress, can be calculated using the load–displacement curve.

A tensile test was conducted at the aforementioned research center, and the velocity of the crosshead was set to 2 mm/min using a UTE-40 machine, FIE-made Universal Testing Machine (UTM). Figure 4 shows various samples subjected to mechanical testing in the lab. Table 1 lists the tensile test results for the respective samples [8–15].

Table 1. Tensile test results for fabricated samples.

S.N.	Sample specification	Max force (N)	Tensile stress (MPa)
1	C-C-W-C-C	29640	185
2	C-A-W-A-C	26980	169
3	A-C-W-C-A	27280	199
4	A-A-W-A-A	20960	142
5	B-B-W-B-B	8460	57
6	B-J-W-J-B	6380	38
7	J-B-W-B-J	10660	64
8	J-J-W-J-J	9220	55
9	Teak Wood	6800	75
10	Aluminum	9100	111

Table 2. Bend test results for fabricated samples.

S.N.	Sample specification	Max force (N)	Bending stress (MPa)
1	C-C-W-C-C	852	2.55
2	C-A-W-A-C	924	3.12
3	A-C-W-C-A	1110	3.76
4	A-A-W-A-A	1866	5.18
5	B-B-W-B-B	828	2.63
6	B-J-W-J-B	1128	3.2
7	J-B-W-B-J	888	2.98
8	J-J-W-J-J	810	2.73
9	Teak Wood	716	2.33
10	Aluminum	296	1.18

Figure 4. Fabricated tensile test samples.

The three-point bending test on the samples was conducted at the stated research center, and the velocity of the crosshead was set at 2 mm/min. The span length was set to 0.6 m using the MCS mechatronics machine. Figure 5 shows the various samples tested in the mechanical testing laboratory. Table 2 lists the bending test results for the respective samples. The experimental results for bending stress show that the composites improved the bending stress. It was found that the maximum bending stress was observed in Sample 4, consisting of an aramid and wood sandwich composite. The bending stress in Sample 4 was found to be 5.18 MPa, whereas it was 1.18 MPa in the aluminum material [16].

Impact Test

The limit of material to resist or absorb the energy before rupture is known as impact strength. The impact strength mainly represents the toughness. The toughness is the ability of a material to absorb energy during fracture. The fracture may be brittle and ductile. Less energy is absorbed by brittle materials compared with ductile materials. The impact strength depends on temperature. The impact energy of materials is reduced at a lower temperature. The impact strength also depends on the size of the sample. The imperfections in materials can act as stress raisers and reduce the energy absorbed. Two types of impact tests are generally applied to engineering materials: the Izod Impact test and the Charpy impact test [17–20].

A pendulum-type Izod impact testing machine was used to evaluate the impact strength. A notch was cut in all samples. Angle of notch is considered to be 45 degrees. The ASTM D2560 standard was applied in designing the sample size. The sample was held in a machine vice, and a pendulum was held at a 90° angle of fall. After pre-setting, the pendulum was released so that the impact occurred. The impact strength was determined by a hammer impact. The energy absorbed was then evaluated. The impact tests on the samples were carried out at the research center, and the pendulum mass was 28.1 kg with an angle of fall of 90° through a distance of 0.825 m.

Figure 6 shows the various samples tested at the mechanical testing lab.

Table 3 presents the impact test results for the respective samples. Table 4 presents the final results of the experimental investigation of all the prepared composite samples.

Table 4 presents the experimental results of the tensile, bending, and impact tests performed on the fabricated composite samples. The experimental results show that Sample 1, which had a maximum tensile load of 29640 N and tensile stress of 185 MPa, outperformed the other samples. In the case of bending, Sample 4 exhibited the maximum bending load of 1866 N and the maximum bending stress of 5.18 MPa. The impact energy was maximum in Sample 3 (impact energy = 13.13 J) among the composites and was lower than that of the teakwood and aluminum samples. This result for the impact energy concludes that the fabricated composites are not suitable for impact loads [21–24].

Figure 5. Fabricated bending test samples.

Figure 6. Fabricated impact test samples.

Table 3. Impact test results for fabricated samples.

S.N.	Sample specification	Impact energy (J)
1	C-C-W-C-C	5.94
2	C-A-W-A-C	11.59
3	A-C-W-C-A	13.13
4	A-A-W-A-A	11.07
5	B-B-W-B-B	1.19
6	B-J-W-J-B	1.58
7	J-B-W-B-J	1.35
8	J-J-W-J-J	0.96
9	Teak Wood	17
10	Aluminum	30

Table 4. Experimental results of composite samples.

S.N.	Sample specification	Tensile test		Bending test		Impact test	
		Max Force (N)	*Tensile Stress (MPa)*	*Max Force (N)*	*Bending Stress (MPa)*	*Impact Load (N)*	*Impact Energy (J)*
1	C-C-W-C-C	29640	185	852	2.55	6500	5.94
2	C-A-W-A-C	26980	169	924	3.12	6500	11.59
3	A-C-W-C-A	27280	199	1110	3.76	6500	13.13
4	A-A-W-A-A	20960	142	1866	5.18	6500	11.07
5	B-B-W-B-B	8460	57	828	2.63	6500	1.19
6	B-J-W-J-B	6380	38	1128	3.2	6500	1.58
7	J-B-W-B-J	10660	64	888	2.98	6500	1.35
8	J-J-W-J-J	9220	55	810	2.73	6500	0.96
9	Teak Wood	6800	75	716	2.33	6500	17
10	Aluminum	9100	111	296	1.18	6500	30

Thus, Sample 1 (having composite symmetric layers of carbon sandwiched with teakwood) is suitable for tensile loading, while Sample 4 (having composite symmetric layers of aramid sandwiched with teakwood) is suitable for flexure loading, and the results of the impact test did not show any improved impact load compared with normal metals. In addition, it was proven that the sandwiched composites made with synthetic fibers have great potential compared to those made with natural fibers.

Finite Element Method

Basic Concept

The finite element method (FEM) is a general-purpose numerical method used to solve a variety of mechanical and structural problems, including static, dynamic, and structural as well as fluid and heat flow problems. Today, the most popular numerical method to analyze the composite structure is the FEM. Many structural software packages are available in engineering fields that can handle composite structures. For the accurate and approximate results of the composite structure consisting of fibers and their layers, the FEM is a better applicable approach. Some finite element software packages are ANSYS (Analysis), NASTRAN (National Aeronautics and Space Administration Structural Analysis), HyperMesh, and SolidWorks [25–30].

The FEM method can be applied in three stages, including pre- processing, processing, and post-processing. In the pre-processing stage, the material properties, geometry, load, and boundary conditions are supplied as input to the software. In software, an in-built automatic meshing is developed by giving the node and element weightages. The analyst will make the decision whether the mesh density is low or high. Once the pre-processing is completed, the processing starts. In processing, the software uses mathematical techniques to generate the element stiffness vector, element load vector, and element displacement vector. After that, the global stiffness vector, global load, and displacement

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vector can be generated by assembling the element vectors mathematically using software. Now, these vectors are combined by equations from, and a solution is obtained for a variable quantity (generally displacements) by any of the numerical methods. The mathematical, physical, and engineering principles are used to find other material properties like stresses and strains. The post-processing will display the results from processing either in tabular form or graphical form. Post-processing allows the analyst to understand the results properly and analyze the results with physical problems needful corrections in input and control that can be performed by the analyst as required for the problem [31–35].

History of FEM

- Hrennikof (1941) and Richard Courant (1942) introduced a framework in which a plastic plate was represented by a collection of small beam elements.
- In the 1950s, the involvement of digital computers helped solve a large number of simultaneous equations.
- Ray Clough was the first to publish the paper introducing the finite element method in the 1960s. The first book on the finite element method was published in 1967 by Zienkiewicz and Chung.
- In the 1970s, the use of supercomputers led to the development of a FEM software package. Most FEM software has evolved in this era.
- In the late 1970s and 1990s, developments in software occurred, and almost all mechanical and structural problems were solved with the help of these software packages.
- From 1990 to the current decade, the FEM software has involved complex fluid flow problems, explicit dynamic problems, vibration analysis problems, and composites analysis problems.

Benefits and Limitations of FEM

FEM is an advanced numerical technology for solving mechanical and structural problems. The main advantage of using FEM is that the modeling of complex geometries and irregular shapes is easy, as various domains are available to discretize the elements. FEM can easily incorporate boundary conditions. The material properties can be easily modified between elements, or higher-order elements can be applied. FEM is a simple and result-oriented numerical technique and is therefore widely used in engineering applications.

Basic Steps in FEM Analysis

Discretization into Elements

First, the materials were specified for the analysis. The physical problem was converted into a solid model using any solid modeling software or design modeler in ANSYS. The solid model was then discretized into a finite number of parts, known as elements. The points that connect the elements are called nodes. The analyst decides the number of elements and nodes required for the analysis. The maximum number of elements and nodes yields accurate results.

Calculation of Element Stiffness, Displacement, and Load Vectors

Once the continuum is divided into nodes and elements, the nodal vectors are calculated using a numerical approach, such as the Galerkin method. The nodal vectors are the nodal displacement vector, nodal stiffness vector, and nodal load vector.

Calculation of Global Stiffness, Displacement, and Load Vectors

The global stiffness vector is obtained by assembling all the nodal stiffness vectors according to the element arrangement. Similarly, the global displacement and load vectors are obtained by assembling the nodal displacement and nodal load vectors, respectively.

Applying Boundary Conditions

The boundary conditions are applied to the nodal vectors to constrain the solution. The boundary conditions are similar to fixed or free support, displacement, loads, pressure, and moments.

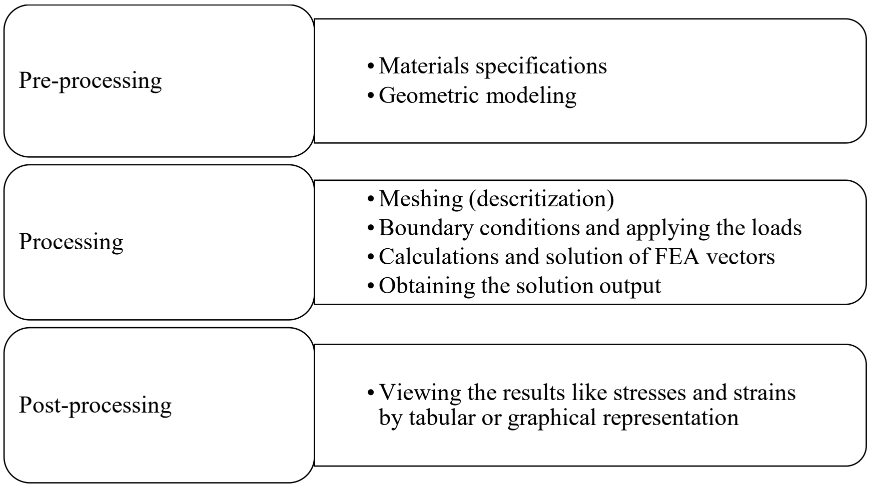

Figure 7. Process flow in FEM [73].

Obtaining the Solution

Numerical techniques, such as the Galerkin method and Gauss elimination method, are applied to obtain the solution. These techniques apply basic engineering, structural, and mechanical principles to obtain the solution. Structural analysis generally provides the solution in the form of strain or stress resultant. The required solution, including stress, strain, deformation, energy, and temperature, is determined using this process.

Post-Processing

This technique represents the solution in tabular and graphical forms. In most software packages, graphical user interfaces are used to obtain graphical results. Figure 7 shows the process flow in FEM.

Assumptions While Performing FEM Analysis

The following assumptions were considered when performing the finite element analysis of the prepared samples for tensile, bending, and impact tests.

- The material properties should be as specified in Table 5.
- The material should be truly orthotropic and otherwise specified, and the layer thickness should be 1 mm, as discussed.
- The applied method of analysis should be program-controlled.
- The results are obtained from FEM software; it may be possible that the results may match experimental or analytical results because of voids in materials.
- The loads were determined from an experimental investigation, and all the loads acting on the samples were point loads.
- The materials that are considered in FEM are truly homogeneous. While the materials considered in the experimental investigation are not homogeneous. Hence, there might be chances of result variation in FEM and experimental investigation.
- Errors arising from the shearing effect or other effects, such as temperature, were neglected.
- The effects due to the elastic properties of epoxy resinize neglected during analysis.

Tensile Test of Composites in FEM

A tensile test reveals the amount of tensile load that a material can endure before failure. The tensile test of composites is a little more complex than the ordinary tensile test of metals in FEM. The ACP toolbox helps deal with composites in FEM. Briefly, ACP is known as ANSYS Composites Prepost. The ACP initially performs ACP Pre to provide primary data to the ANSYS software, such as material properties, geometry, meshing data, and composite setup. The setup data are then provided to the static analysis toolbox, and the results are obtained as the structural analysis. The ACP post is required to analyze and determine the output data either graphically or in tabular form.

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RESULTS AND DISCUSSION

The present study investigates the behavior of composite materials under tensile, bending, and impact loads. The samples were prepared according to the respective ASTM standards, and an experimental investigation was conducted at an NABL-calibrated research and testing laboratory in Indore. The results of the evaluations of the tensile, bending, and impact strengths are discussed in this section.

Tensile Test

The tensile test is utilized to understand the tensile behavior of materials. Tensile tests are helpful in determining the tensile data and obtaining the tensile force or strength before the material fails. The tensile test is necessary to evaluate the other mechanical properties.

In the present work, the tensile tests of various composite materials were evaluated using a UTM machine. The size of the specimen was considered to be length = 250 mm, width = 20 mm, and thickness = 10 mm. The composites were prepared by considering a 0° orientation of carbon fiber, aramid fiber, jute fiber, and banana fiber. These fibers were sandwiched with a simple wood sample as per ASTM D3039 to observe or improve the tensile properties of the prepared composite samples.

Table 6 and Figure 8 show the FEM and experimental results of the prepared composite samples and the percent error in the results of the FEM and experimental methods. It has been seen from Table 6 that the maximum force is withstood by Sample 1 and is equal to 29640 N. The maximum value of the load indicates that the material has good strength. Also, it was found that the Sample 4 made by aramid fibers has a very low percent error in FEM and experimental stress values, but the tensile load is just 20960, which is less than that of Sample 1 by 8680 N. Sample 1 has a tensile load of 29640 N and has a minimum percentage error of 2.78. The other composite samples had good strength; however, they exhibited considerable percent errors. Therefore, it may result that Sample 1 is better in comparing within fabricated composites.

Table 5. Composite material properties for the finite element method.

S.N.	Properties	Teak wood	Aluminum	Carbon fiber	Aramid fiber	Banana fiber	Jute fiber
1	Density (kg/m^3)	639	2770	1490	1380	1350	1350
2	Ex (GPa)	10.684	71.00	121	75	38	60
3	Ey (GPa)	10.684	71.00	8.6	6.0	3.6	3.0
4	Ez (GPa)	10.684	71.00	8.6	6.0	3.6	3.0
5	V_{xy}	0.35	0.35	0.27	0.28	0.28	0.11
6	V_{yz}	0.35	0.35	0.4	0.4	0.3	0.01
7	V_{xz}	0.35	0.35	0.27	0.28	0.28	0.11
8	G_{xy} (GPa)	3.957	26.69	4.7	2.0	1.32	1.2
9	G_{yz} (GPa)	3.957	26.69	3.1	1.32	1.2	1.0
10	G_{xz} (GPa)	3.957	26.69	4.7	2.0	1.32	1.2

Table 6. Tensile strength results from FEM and experimental methods.

S.N.	Sample specification	Tensile strength (MPa)			Error (%)
		Max force (N)	*Finite element method*	*Exp.*	
1	C-C-W-C-C	29640	179.86	185	2.78
2	C-A-W-A-C	26980	180.79	169	6.52
3	A-C-W-C-A	27280	149.41	199	24.92
4	A-A-W-A-A	20960	140.05	142	1.37
5	B-B-W-B-B	8460	65.20	57	12.58
6	B-J-W-J-B	6380	40.39	38	5.92
7	J-B-W-B-J	10660	85.16	64	24.85
8	J-J-W-J-J	9220	64.43	55	14.64
9	Teak Wood	6800	65.23	75	13.03
10	Aluminum	9100	86.25	111	22.30

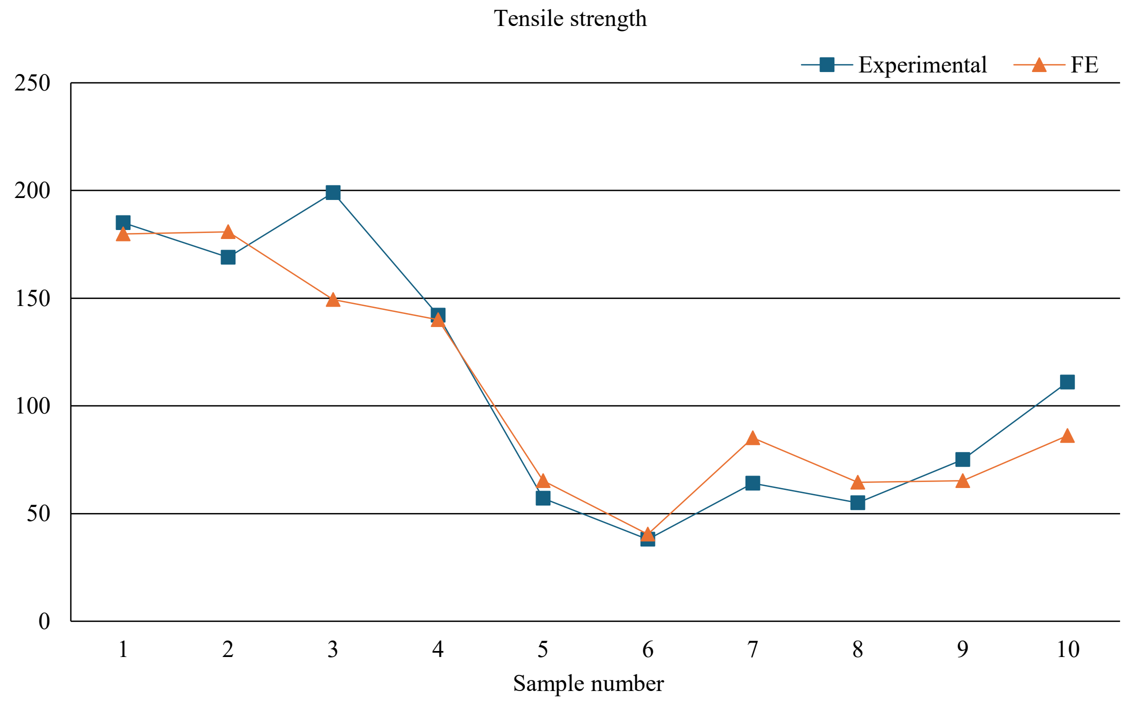

Figure 8. Tensile strength results of all samples.

When Sample 1 was compared with normal materials, such as teakwood and aluminum, it was found that the tensile strength of Sample 1 was 2.5 times higher than that of teakwood and 1.5 times higher than that of aluminum. The results show that the addition of layers of carbon fiber increases the tensile strength of teakwood.

The tensile analysis of composite materials also reveals that natural fiber composite materials have lower tensile strengths than normal materials. This demonstrates that synthetic fibers have great potential for improving the tensile strength of natural fibers.

Bending Test

Engineers often seek the flexure behavior of composite materials for technical applications; however, it is complex in nature because of the presence of many in-plane forces during the flexure test. Bending tests can be applied to composite materials. The tensile strength is observed when the load is along the fibers; however, in bending, the bending load is in the transverse direction of the fibers.

The bending test has been applied to the selected samples prepared. The bending test was performed in UTM by taking a span length of 0.6 m. The ASTM D7264 standard was followed for the composite experiments. Table 7 and Figure 9 present the bending strength results for various samples. The results show that the maximum bending strength is 6.45 MPa by FEA and 5.18 MPa by the experimental method in Sample 4, with a percent error of 19.69. In addition, the maximum load sustained by Sample 4 was 1866 N. Therefore, Sample 4 was the best among the composites.

When compared to teakwood and aluminum materials, the bending strength of Sample 4 is more than that of teakwood and less than that of aluminum.

Impact Test

Impact testing is another important type of mechanical test. Impact testing determines the energy absorbed by a material before it fractures. The impact test was performed as per ASTM D2564 to inspect the energy absorbed during the impact. Izod and Charpy tests were applied to composite and metal samples, respectively, in accordance with the standards. The specimen size was taken as 70 mm length, 12.7 mm width, with a notch at the center, and 10 mm thickness. The results are tabulated in Table 8 and shown in Figure 10.

Table 7. Bending strength results from FEM and experimental methods.

S.N.	Sample specification	Bending strength (MPa)			Error (%)
		Max force (N)	*Finite element method*	*Exp.*	
1	C-C-W-C-C	852	2.98	2.55	14.42
2	C-A-W-A-C	924	3.77	3.12	17.24
3	A-C-W-C-A	1110	3.14	3.76	16.49
4	A-A-W-A-A	1866	6.45	5.18	19.69
5	B-B-W-B-B	828	2.76	2.63	4.71
6	B-J-W-J-B	1128	3.13	3.2	2.19
7	J-B-W-B-J	888	3.47	2.98	14.12
8	J-J-W-J-J	810	2.75	2.73	0.73
9	Teak Wood	716	1.43	2.33	38.63
10	Aluminum	296	9.91	1.18	88.09

Table 8. Impact energy results by FEM and experimental methods.

S.N.	Sample specification	Impact energy (J)			Error (%)
		Max. force (N)	*Finite element method*	*Exp.*	
1	C-C-W-C-C	6500	5.03	5.94	15.32
2	C-A-W-A-C	6500	5.84	11.59	49.61
3	A-C-W-C-A	6500	5.91	13.13	54.99
4	A-A-W-A-A	6500	7.09	11.07	35.95
5	B-B-W-B-B	6500	9.59	1.19	87.59
6	B-J-W-J-B	6500	8.96	1.58	82.37
7	J-B-W-B-J	6500	8.98	1.35	84.97
8	J-J-W-J-J	6500	8.53	0.96	88.75
9	Teak Wood	6500	15.34	17	9.76
10	Aluminum	6500	32.77	30	8.45

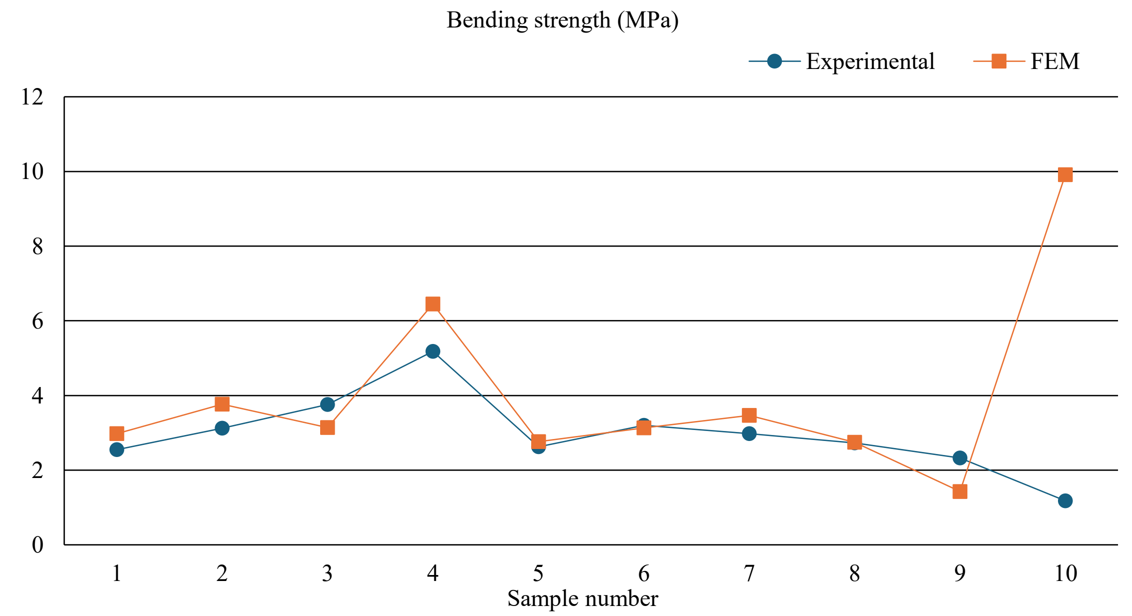

Figure 9. Bending strength results of all samples.

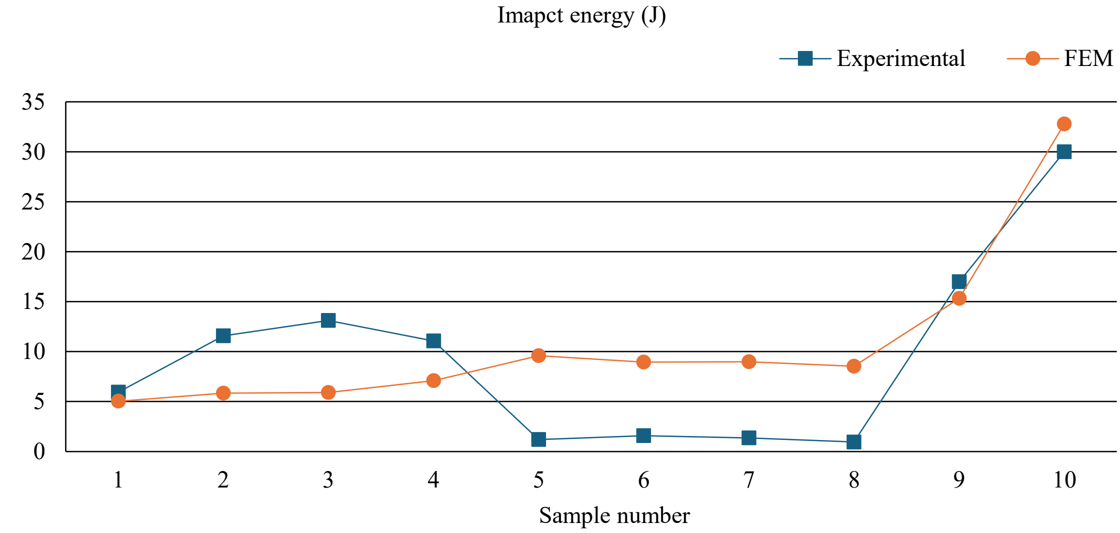

Figure 10. Impact energy results of all samples.

CONCLUSION

The experimental findings unequivocally show that fiber sandwiching significantly enhances the mechanical performance of teakwood, particularly under tensile and flexural loading. The carbon fiber–teakwood–carbon fiber (C–C–W–C–C) configuration demonstrated the highest tensile strength among all the manufactured specimens, attaining approximately 2.5 times the strength of teakwood and approximately 1.5 times that of aluminum, demonstrating the superior load-carrying capacity of carbon fiber-reinforced sandwich composites. The aramid fiber–teakwood–aramid fiber (A-A-W-A-A) composite exhibited the highest bending strength with respect to flexural performance, indicating that aramid fibers play a major role in resisting transverse loading and deformation. Therefore, sandwich composites based on aramid are especially well-suited for applications where bending loads predominate.

When compared with traditional materials, such as aluminum and teakwood, the impact test results showed that the fabricated composites had comparatively lower impact energy absorption. This suggests that although FSCMs perform very well under tensile and bending loads, their use in high-impact situations is restricted until additional material modifications are made.

The reliability of numerical modeling for forecasting the mechanical behavior of multi-layer composite systems was validated by the finite element analysis (FEA) results, which closely matched the experimental findings with acceptable percentage errors. The assumptions of material homogeneity, perfect bonding conditions, and disregard for manufacturing flaws, such as voids, can explain the small differences between the FEA and experimental values. Based on the overall findings of the study, sandwich composites made of synthetic fibers perform better mechanically than those made of natural fibers. The proposed FSCMs have great potential for lightweight structural applications in the transportation, automotive, and aerospace industries, where flexural rigidity and a high strength-to-weight ratio are essential. Future research may focus on enhancing impact resistance using sophisticated manufacturing processes, alternative core materials, or hybrid fiber stacking.

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