Evaluation of Mechanical Properties of Metallic Fiber/Carbon/Glass Woven Reinforced Polymer Composites

Jayachandran J [1], Ginu D[2]

[1]PG *Student, Manufacturing Engineering, Bethlahem Institute of Engineering, Karungal, Kanyakumari*

[2]*Assistant Professor, Department of Mechanical Engineering, Bethlahem Institute of Engineering, Kanyakumari*

Abstract - Fibres made of metal are very strong. Glass fibre is a key component in the design of numerous composite applications. High stiffness, high tensile strength, low weight, good chemical resistance, high temperature tolerance, and minimal thermal expansion are only a few of the benefits of carbon fibres. Thus, in the current study, a hybrid composite material is created by varying the combinations of glass, carbon, and metallic fibres. For every combination, the tensile and impact stress characterizations were established. It is employed in the creation of Glass-Metallic-Carbon composites, which are utilised in sports and auto bumper applications. The composite laminates had dimensions of 30 cm by 30 cm by 3 mm and were made via compression moulding and hand layup. For the tensile and impact tests, the ASTM D 3039 (250 x 25 x 3) and ASTM D256 (64 x 12.7 x 3.2 mm) standards were adhered to. For the flexion and compression testing, the ASTM D 3410 (140 x 25 x 3 mm) and ASTM D 7264 (16 x 13 x 3 mm) standards were adhered to, respectively.

Key Words: Mettalic Fibre, Carbon Fibre, Glass Fibre, Hand layup, Mechanical Test.

1. INTRODUCTION

Combining two or more different materials to create a superior (and frequently stronger) product is known as a composite. Composite materials have been used by humans for thousands of years to construct everything from basic shelters to complex electrical equipment. Although the earliest composites were formed from natural materials like straw and mud, modern composites are generated in a lab using synthetic ingredients. There are a variety of reasons why the new material might be chosen over the old one, some of which include its increased strength, reduced weight, or lower cost. Constituent materials are the discrete materials that make up composites. Constituent elements fall into two basic categories: reinforcement and matrix (binder). Each type must have at least one piece. The reinforcing materials are surrounded by and supported by the matrix material, which keeps them in their proper relative places. The unique mechanical and physical qualities of the reinforcements are imparted to improve the matrix properties. The large range of matrix and reinforcing elements enables the product or structure designer to select the best combination, while a synergism generates material qualities not achievable from the individual constituent materials.

2. MATERIALS

2.1 Carbon fiber

Carbon fiber is a lightweight, high-strength material known for its excellent strength-to-weight ratio and durability. It is composed of thin strands of carbon atoms, typically bound together by polymer resins. These carbon fibers are woven into a fabric or combined with other materials to create composites with specific properties.

characteristics of carbon fiber include:

Strength: Carbon fiber is renowned for its high tensile strength, making it stronger than many traditional materials like steel, while being significantly lighter.

Lightweight: Carbon fiber composites are lightweight, making them ideal for applications where weight reduction is critical, such as in aerospace, automotive, and sports equipment.

Stiffness: Carbon fiber is highly stiff, providing excellent structural rigidity. This property makes it suitable for applications where stiffness is essential, such as in the construction of high-performance vehicles and sporting goods.

Chemical Resistance: Carbon fiber is resistant to chemicals, including corrosive substances, which enhances its durability in various environments.

Temperature Resistance: Carbon fiber exhibits good resistance to high temperatures, making it suitable for applications in industries such as aerospace and motorsports. Low Thermal Expansion: Carbon fiber has a low coefficient of thermal expansion, meaning it retains its shape and dimensions even in changing temperature conditions.

Electrical Conductivity: Carbon fiber is electrically conductive, which can be an advantage in certain applications, but it may also require additional measures to insulate it electrically when needed.

2.2 Metallic Fiber

Metallic fibers refer to fibers made from metals or metal- coated materials. These fibers are often thin and flexible, similar to traditional textile fibers, but they are composed of metallic elements. There are several ways metallic fibers can be produced, and they are used in various applications due to their unique properties.

Production Methods:

Metallization: In this process, non-metallic fibers are coated with a thin layer of metal through techniques like vapor deposition or sputtering.

Extrusion: Metallic fibers can also be directly extruded from molten metal or metal alloys.

Properties:

Conductivity: Metallic fibers are electrically conductive, making them suitable for applications in electronics, smart textiles, and electromagnetic shielding.

Thermal Conductivity: Metals generally have high thermal conductivity, and metallic fibers can be used in applications where efficient heat transfer is important.

Strength: Depending on the metal used, metallic fibers can exhibit high tensile strength.

Applications:

Textiles: Metallic fibers are sometimes incorporated into fabrics to add unique properties such as conductivity, heat dissipation, or a metallic appearance. They are used in clothing, accessories, and industrial textiles.

Electronics: Metallic fibers are used in the production of flexible and conductive textiles for applications like wearable technology and electronic textiles (e-textiles).

Industrial Applications: Metallic fibers can be employed in industrial settings for purposes such as filtration, reinforcement in composites, and conductive elements in various products.

2.3 Glass Fiber

Glass fiber, also known as fiberglass, is a material made from extremely fine fibers of glass. These fibers can be woven into fabrics or used in the form of mats, and they are often combined with resins to create composite materials with specific properties. Glass fiber composites are known for their strength, durability, and versatility, and they are used in various industries for a wide range of applications.

Types of Glass Fiber:

E-Glass (electrical glass): Commonly used for general- purpose applications, E-Glass is known for its electrical insulation properties.

S-Glass (structural glass): S-Glass has higher strength and stiffness compared to E-Glass and is often used in applications where superior mechanical properties are required.

C-Glass (chemical-resistant glass): C-Glass is designed to provide resistance to chemical corrosion and is used in applications where exposure to harsh chemicals is a concern. Properties:

High Strength: Glass fibers exhibit high tensile strength, making them suitable for reinforcing materials in composites.

Low Weight: Glass fiber composites are lightweight, which is beneficial in applications where weight reduction is important.

Corrosion Resistance: Glass fibers are resistant to corrosion, making them suitable for use in harsh environments.

Applications:

Construction: Glass fiber composites are widely used in the construction industry for reinforcing concrete, providing strength and durability to structures.

Automotive: Glass fiber-reinforced plastics (GFRP) are used in automotive components to reduce weight and improve fuel efficiency.

Aerospace: Glass fibers are used in the aerospace industry for components that require high strength and light weight. Boats and Marine Applications: Fiberglass is commonly used in boat construction due to its resistance to water and corrosion.
Wind Energy: Glass fiber composites are used in the manufacturing of wind turbine blades.

2.4 Polyester resin

Polyester resin is a type of synthetic resin that is commonly used in the production of a wide range of products, especially in the field of composite materials. It is part of the larger family of thermosetting polymers, which means it undergoes a chemical reaction to harden and become rigid. Polyester resin is known for its versatility, ease of use, and affordability.
Types of Polyester Resin:
Unsaturated Polyester Resin (UPR): This is the most common type of polyester resin used in composites. It contains unsaturated bonds in its molecular structure, allowing it to undergo crosslinking reactions during curing. Orthophthalic Polyester Resin: A general-purpose type used in a variety of applications.
Isophthalic Polyester Resin: Exhibits enhanced resistance to water, chemicals, and heat compared to orthophthalic resin.
Vinylester Resin: A modified form of polyester resin that includes reactive sites similar to those found in vinyl esters. Vinylester resins offer improved mechanical properties and chemical resistance.
Properties:
Versatility: Polyester resin can be used with various reinforcing materials such as fiberglass, carbon fiber, or aramid fibers to produce composite materials with different mechanical properties.
Adhesion: It generally adheres well to a variety of materials, making it suitable for bonding and laminating applications. Low Cost: Polyester resin is cost-effective compared to some other types of resins, making it a popular choice for a range of applications.
Shrinkage: During the curing process, polyester resin may experience some shrinkage, which needs to be taken into account in manufacturing processes.
Applications:
Composite Materials: Polyester resin is widely used in the production of fiberglass-reinforced composite materials for applications such as boat building, automotive parts, and construction components.
Casting and Molding: It is used for casting various shapes and molds in industries such as art, model making, and prototyping.
Coatings: Polyester resin can be used as a coating material, providing protection and a smooth finish to surfaces.

2.5 Methyl ethyl ketone (MEK)

Methyl ethyl ketone (MEK), also known as butanone, is a colorless, flammable liquid with a sweet odor. It is a ketone, which is a type of organic compound characterized by a carbonyl group (C=O) bonded to two alkyl groups. MEK has various industrial applications due to its solvent properties, low boiling point, and chemical reactivity.
Physical Properties:
Boiling Point: MEK has a relatively low boiling point of around 79 degrees Celsius (174 degrees Fahrenheit).
Density: It has a density of approximately 0.805 grams per milliliter.
Solubility: MEK is miscible with a wide range of organic solvents and is moderately soluble in water.
Uses:
Solvent: MEK is primarily used as an industrial solvent for paints, coatings, adhesives, and varnishes. It is valued for its ability to dissolve a variety of substances.
Adhesive Production: MEK is used in the production of certain adhesives.
Surface Coatings: It is employed in the formulation of surface coatings, including those for wood, metal, and plastics.
Extraction: MEK is used in the extraction of certain chemicals and pharmaceuticals.

2.6 Cobalt

Cobalt is frequently used as a catalyst in various chemical reactions due to its ability to facilitate and control the rate of reactions. As a catalyst, cobalt participates in the reaction but is not consumed, meaning it can be recovered at the end of the process. Here are some common applications of cobalt as a catalyst:
Hydrogenation Reactions: Cobalt catalysts are employed in the hydrogenation of organic compounds,

where hydrogen is added to unsaturated molecules. For example, cobalt catalysts are used in the hydrogenation of vegetable oils to produce fats for food applications.

Oxidation Reactions: Cobalt-based catalysts can be used in oxidation reactions, such as the oxidation of alcohols to aldehydes or ketones. These catalysts play a role in the activation of molecular oxygen during the reaction.

Polymerization Reactions: Cobalt compounds are used as catalysts in the polymerization of certain monomers. For instance, cobalt carboxylates are employed in the production of polyesters.

Hydroformylation Reactions: Cobalt catalysts are utilized in hydroformylation reactions, a process where olefins (alkenes) react with carbon monoxide and hydrogen to form aldehydes.

Catalytic Cracking in Petroleum Refining: Cobalt-based catalysts are used in catalytic cracking processes in petroleum refining to break down larger hydrocarbons into smaller, more valuable products like gasoline.

Electrochemical Reactions: Cobalt compounds can serve as catalysts in various electrochemical reactions, such as oxygen reduction reactions in fuel cells.

Ring-Closing Metathesis: Cobalt catalysts are involved in ring-closing metathesis reactions, a type of chemical transformation used in the synthesis of organic compounds. Water-Gas Shift Reaction: Cobalt catalysts are employed in the water-gas shift reaction, where carbon monoxide and water react to produce carbon dioxide and hydrogen. This reaction is relevant in processes like hydrogen production for fuel cells.

3. EXPERIMENTAL WORK

3.1 Hand Lay-Up Method

3.1.1 Procedure:

Prepare the Mold: Ensure that the mold or tooling is clean and properly prepared. Apply a release agent to the mold surface if necessary to facilitate demolding later.

Cutting Fibers: Cut metallic, carbon, and glass fibers to the desired dimensions based on the design and layering sequence.

Layering: Begin layering the fibers in the mold according to the desired laminate structure. The order and orientation of the layers will impact the mechanical properties of the final composite. Ensure that each layer is well-aligned, and overlaps or voids are minimized.

Mix Resin: Mix the epoxy resin system or the chosen resin with the appropriate hardener or catalyst. Measure and mix the components in the correct ratios using a weighing scale.

Wet-out Fibers: Apply the mixed resin to each layer of fibers using brushes or rollers, ensuring thorough wetting of the fibers. Make sure that there are no dry spots, and the resin saturates the fibers completely.

Consolidation: Use rollers, squeegees, or brushes to consolidate the layers and remove any trapped air. Continue the process, adding more layers and resin as needed.

Curing: Allow the laminate to cure according to the resin manufacturer's specifications. This may involve a specific curing temperature and time. The curing process may take place at room temperature or in a controlled oven, depending on the resin system.

Demolding: Once cured, demold the laminate from the mold. The release agent, if used, should aid in easy demolding.

3.2 Mould Preparation

First of all the mould for the composite is prepared. Moulds of size 400 x 300 x 8 mm for the preparation of required composite. A clean smoothed surfaced wooden board is taken and washed thoroughly. A cover to the wooden board with a non-reactive thin plastic sheet.

Fig – 1 Mould Box

3.3 Fiber Preparation

Carbon, Metallic and Glass Fiber which are brought and dried with sunlight. Then the aggregations are gently dispersed with hand sitting patiently. After that it is measured for proper size and kept.

3.4 Polymer-Hardner Mixture Preparation

For the making of good composite the measurement of the samples should be accurate and the mixture should be very uniform. We take 600gm of polymer which we have calculated earlier and 30 spoon of its hardener. Then this mixture is stirred thoroughly till it becomes a bit warm. Bit extra amount of hardener is taken for the wastage in the process. Hardener should take very minutely because little extra amount of hardener can spoil the composite.

Fig – 2 Polymer-Hardner Mixture Preparation

3.5 Layers in Prepared FRP Composite

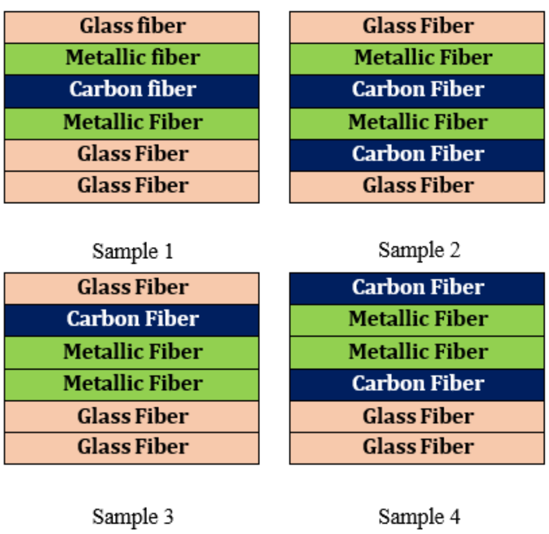


Fig -1: Prepared Specimen

Begin the lay-up process by placing the first layer of metallic fibers onto the resin-coated mold. Apply additional resin over the metallic fibers using a brush or roller to impregnate the fibers thoroughly. Add a layer of carbon fibers over the metallic layer, applying resin between each layer. Follow this with a layer of glass fibers, again applying resin to ensure saturation. Continue the layering process until the desired thickness and fiber orientation are achieved.

4. MECHANICAL TESTING

4.1 Tensile testing

Tensile testing, also known as tension testing, is a fundamental mechanical test used to evaluate the mechanical properties of materials. The primary purpose of tensile testing is to determine the material's behavior under axial stretching forces. This test helps engineers and scientists understand how a material responds to stress, strain, and deformation.

Equipment and Setup:

Tensile Testing Machine: This machine applies a uniaxial force to a specimen 1,2,3,4 and measures the resulting deformation.

Specimen: The material sample that undergoes testing. The specimen is typically a standardized shape and size according to testing standards. The ultimate tensile strength, yield strength, elongation, and Poisson's ratio of plastics are all measured by the ASTM D3039.

Testing Procedure:

Specimen Preparation: The material is prepared in a specific shape and size according to testing standards.

Mounting: The specimen is mounted onto the testing machine, and initial measurements such as specimen dimensions are recorded.

Loading: The machine applies a gradually increasing force to the specimen until it fractures. The applied force and corresponding deformation are continuously recorded.

Data Analysis: The stress-strain curve is generated from the recorded data. This curve illustrates how the material responds to increasing stress until failure.

4.2 Compression testing

Compression testing is a mechanical testing method that assesses the behavior of materials under compressive loads. In contrast to tensile testing, where forces act to elongate or stretch a material, compression testing involves applying forces that act to compress or shorten the material. This type of testing is essential for understanding how materials respond to loads that push or squeeze them.

Equipment and Setup:

Compression Testing Machine: Similar to a tensile testing machine but designed to apply compressive forces.

Specimen: The material sample is prepared in a specific shape and size, often cylindrical or cuboidal, based on testing standards.
Testing Procedure:
Specimen Preparation: The material is shaped into a specimen according to testing standards.
Mounting: The specimen is placed in the compression testing machine, and initial measurements such as specimen dimensions are recorded.
Loading: The machine applies a gradually increasing compressive force to the specimen until it deforms or fractures. The applied force and corresponding deformation are continuously recorded.
Data Analysis: The stress-strain curve for compression testing is generated, illustrating how the material responds to increasing compressive stress.

4.3 Flexural testing

Flexural testing, also known as bending testing or transverse testing, is a mechanical test used to evaluate the flexural or bending properties of materials. This type of testing assesses a material's ability to resist deformation under applied bending forces. Flexural tests are commonly performed on materials like metals, plastics, ceramics, and composites, where bending strength and stiffness are critical factors.

5. EXPERIMENTAL RESULTS

5.1 Tensile Testing

5.1.1 Specimen 1

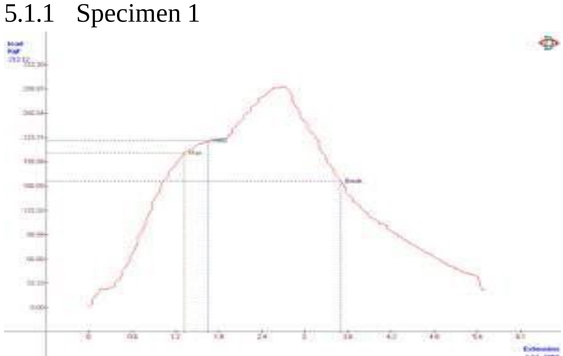


Table -1 Obtained Results

Results	Value	
Area	1.08	cm²
Yield Force	229.10	Kg
Yield Elongation	1.66	mm
Break Force	173.4	Kg
Break Elongation	3.53	mm
Tensile Strength at Yield	212.13	Kg/cm²
Tensile Strength at Break	160.55	Kg/cm²
% Elongation	4.41	%

5.1.2 Specimen 2

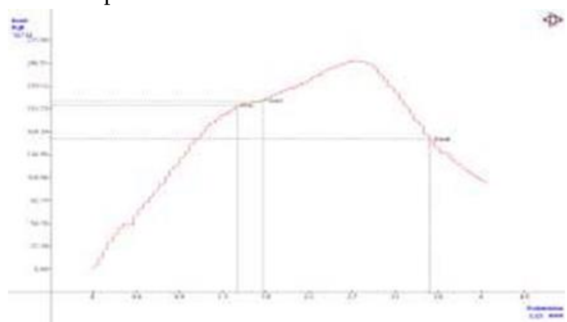


Table -2 Obtained Results

Results	Value	
Area	1.08	cm²
Yield Force	201.11	Kg
Yield Elongation	1.76	mm
Break Force	155.3	Kg
Break Elongation	3.49	mm
Tensile Strength at Yield	186.21	Kg/cm²
Tensile Strength at Break	143.83	Kg/cm²
% Elongation	4.37	%

5.1.3 Specimen 3

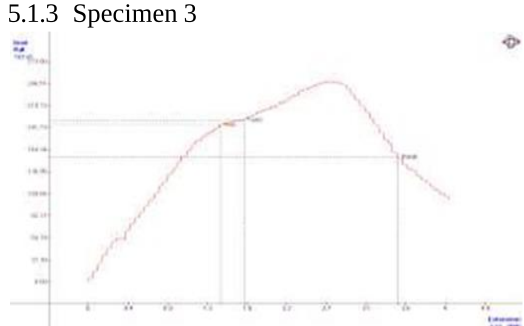
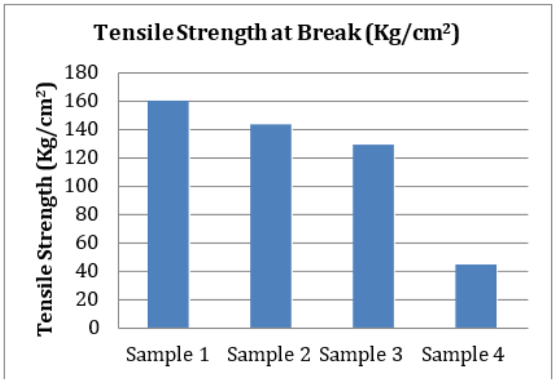


Table -3 Obtained Results

Results	Value	
Area	1.20	cm²
Yield Force	201.11	Kg
Yield Elongation	1.76	mm
Break Force	155.3	Kg
Break Elongation	3.49	mm

Tensile Strength at Yield	167.59	Kg/cm²
Tensile Strength at Break	129.45	Kg/cm²
% Elongation	4.37	%



Graph – 1 Tensile Strength

By dividing the break load by the specimen's cross-sectional area, the breaking stress on each specimen was computed. The specimen containing metallic fibre exhibited superior tensile stress strength in both carbon and E-glass reinforcement, despite the composite's breaking strength being solely determined by the fiber's modulus. This was attributed to Specimen 1's higher modulus value. It demonstrates the importance of the brittleness property in the system because the Specimen 1 brittleness property significantly lessens the elongation at break. Specimen 1's strength for metallic carbon with E-glass fibre reinforcement is 160.55 kg/cm².

5.2 Compressive Strength

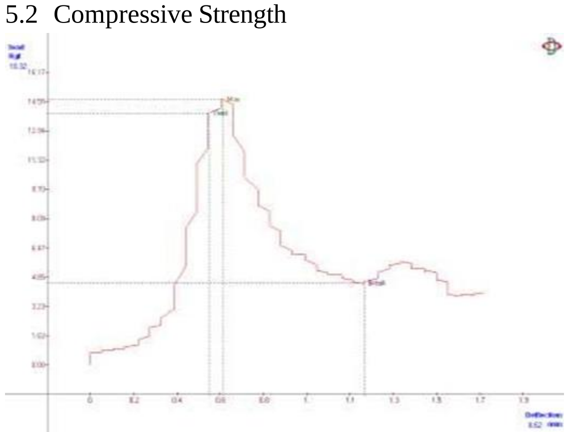


Table -4 Obtained Results

Results	Value	Unit
Area	3.00	cm²
Yield Force	13.92	Kg
Maximum Force	4.5	Kg
Total Deflection	1.21	mm
Compressive Yield strength	4.64	Kg/cm²
Compressive strength	1.51	Kg/cm²
% Deflection	2.42	

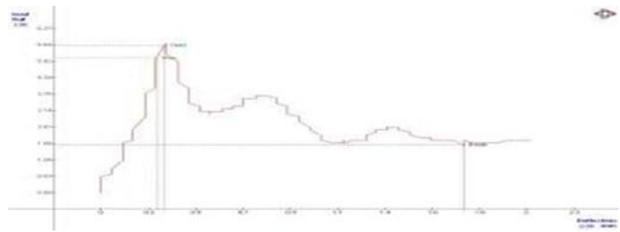


Table -5 Obtained Results

Results	Value	Unit
Area	3.00	cm²
Yield Force	5.63	Kg
Maximum Force	1.8	Kg
Total Deflection	1.74	mm
Compressive Yield strength	1.88	Kg/cm²
Compressive strength	0.61	Kg/cm²
% Deflection	3.48	

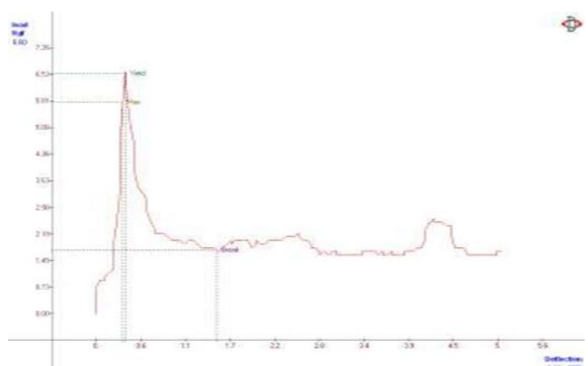
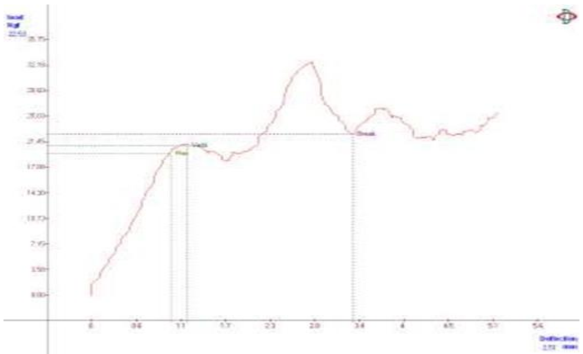


Table -6 Obtained Results

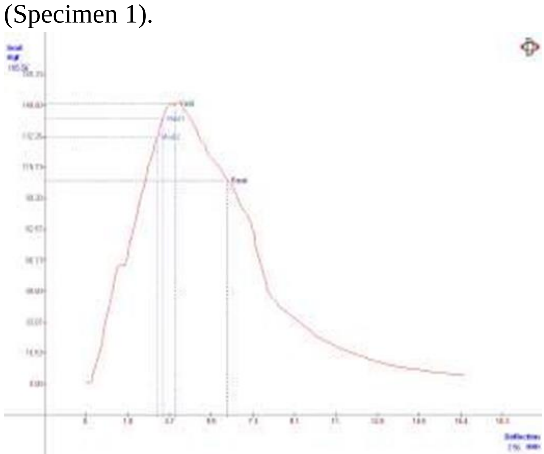
Results	Value	Unit
Area	3.00	cm²
Yield Force	6.56	Kg
Maximum Force	1.7	Kg
Total Deflection	1.51	mm
Compressive Yield strength	2.19	Kg/cm²
Compressive strength	0.58	Kg/cm²
% Deflection	3.02	



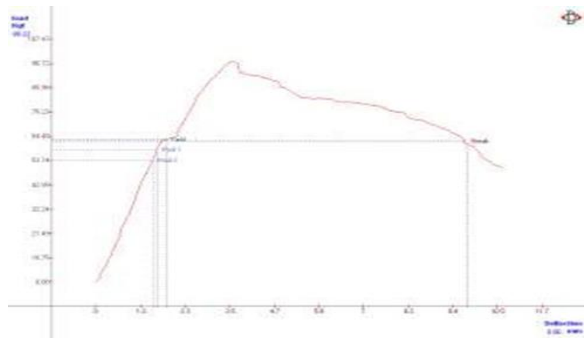
Obtained Results

Results	Value	Unit
Area	3.00	cm^2
Yield Force	20.93	Kg
Maximum Force	22.5	Kg
Total Deflection	3.31	mm
Compressive Yield strength	6.98	Kg/cm^2
Compressive strength	7.51	Kg/cm^2
% Deflection	6.62	

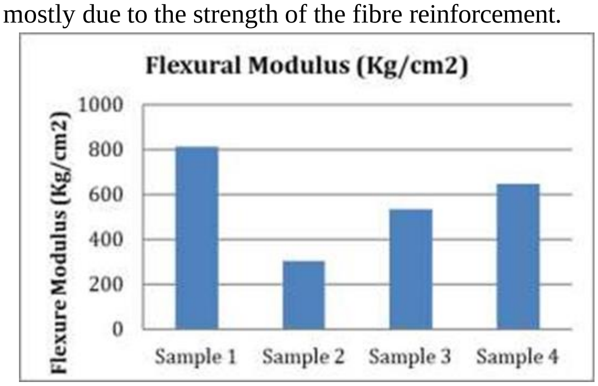
A compressive stress of 4.64 kg/cm^2 is recorded in the neat metallic glass fibre composite and carbon fibre composite, according to the results. With metallic, carbon fibre, and glass fibre composites, a similar declining trend in compressive modulus is seen (Specimen 1).



Mod 1 Force	141.61	Kg
Mode 1 Deflection	3.37	Mm
Mod 2 Force	131.84	Kg
Mod2 Deflection	3.13	mm
Stress 1	23.60	N/mm^2
Stress 2	21.97	N/mm^2
Flexural Modules	814.30	



The metallic, glass, and carbon fibre reinforced composites' flexural stress and flexural modulus are shown in the flexural as well as similar trend of flexure graphs. The flexural stress and flexural modulus of the composite are significantly reduced by the addition of metallic to the PER matrix. These reinforced composites have significantly varying elongations, mostly due to the strength of the fibre reinforcement.



Graph – 2 Flexure Modulus

3. CONCLUSIONS

The advantages of natural fibres for the environment and economy are making them more and more popular as reinforcement for polymer composites. These fibres have a larger water-uptake capacity and a lower strength than inorganic fibres, which are drawbacks that must be overcome to fully utilise them as reinforcement. Synthetic fibre is a simple way to improve these attributes. The best mechanical properties can be found when synthetic fibre is positioned between a glass/metallic fibre laminate. Furthermore, to prevent natural fibres from deteriorating and to boost material strength, glass and metallic fibres function as a barrier against unfavorable environments. Compared to natural fibre reinforced polymer composites, the mechanical properties of carbon-glass/metallic fibre reinforced polymer composites have been evaluated in this study, and the useful results have been discovered to encourage usage of such materials in various applications. Researchers may be encouraged by this work to use synthetic fibres from specimen 1 in order to improve mechanical strength.

REFERENCES

[1] Sandeep Kumar, “Effect of Hybridization of Glass/Kevlar Fiber on Mechanical Properties of Bast Reinforced Polymer Composites: A Review” American Journal of Polymer Science & Engineering.

[2] R.Sakthivel, “Experimental Investigation and Analysis a Mechanical Properties of Hybrid Polymer Composite Plates” International Journal of Engineering Trends and Technology (IJETT) – Volume 9 Number 8 - Mar 2014.

[3] R Yahaya, “Mechanical performance of woven kenaf- Kevlar hybrid composites” Journal of Reinforced Plastics and Composites 2014.

[4] Gangadhar M Kanaginahal, “Microstructural Study and Evaluation of Few Mechanical Properties of Hybrid Composites” Advanced Materials Manufacturing & Characterization Vol 7 Issue 1 (2017).

[5] Girish Gautam, “Mechanical Characterization of Kevlar-29 Fiber Reinforced Polymer Composite” ELK Asia Pacific Journals – 978-93-85537-06-6 ARIMPIE -2017.