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A Comparitive Study of Mechanical Properties and Chemical Stability of Rubber Incorporated Carbon / Epoxy Composites and Glass / Epoxy Composites

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Abstract
Composite materials have gained significant importance in engineering applications due to their high strength-to-weight ratio, corrosion resistance, and superior mechanical performance. The present study focuses on a comparative investigation of the mechanical properties and chemical stability of rubber incorporated carbon fiber reinforced epoxy composites and rubber incorporated glass fiber reinforced epoxy composites. Carbon fiber and glass fiber were used as reinforcement materials with epoxy resin as the matrix, while 5% rubber particles were incorporated to improve toughness and resistance to crack propagation. The composites were fabricated using the hand lay-up method followed by vacuum bag moulding and post-curing techniques. Six layers of bidirectional carbon fiber and glass fiber were used separately to prepare two composite samples. Mechanical properties such as tensile strength, tensile modulus, flexural strength flexural modulus, and percentage tensile elongation were evaluated using Universal Testing Machine (UTM) according to ASTM standards. Chemical stability tests were also conducted by exposing the specimens to water, hydrochloric acid, and sodium hydroxide solutions. The experimental results showed that the carbon fiber-reinforced epoxy composite with 5% rubber exhibited superior tensile strength (449.589 MPa), tensile modulus (431.886 MPa), flexural strength (10.288 MPa), and flexural modulus (4.187 MPa) compared to the glass fiber-reinforced composite. However, the glass fiber composite exhibited a higher percentage elongation, indicating greater ductility. Both composites exhibited excellent chemical stability, with no significant weight change upon exposure to water, acid, or alkaline environments. The study concludes that rubber-incorporated carbon fiber epoxy composites possess enhanced mechanical performance and stiffness, while both composites demonstrate excellent chemical resistance suitable for structural and engineering applications.

Keywords: Carbon Fiber Composite**,** Glass Fiber Composite**,** Epoxy Resin**,** Rubber Toughening, Mechanical Properties

1. Introduction

1. Composites

Composite materials have been used for many years, but their industrial importance increased greatly in the 1960s with the development of polymer-based composites. Today, they are widely used in automotive, aerospace, marine, sports, consumer goods, and oil industries because of their lightweight and high-performance properties. Replacing steel with composites can reduce weight by 60–80%, while replacing aluminum can reduce it by 20–50%.A composite material is formed by combining two or more materials to achieve improved properties. In fibre-reinforced composites, the materials remain mechanically distinct while working together to provide enhanced performance. Natural examples include wood, where cellulose fibres are embedded in lignin, and ancient clay reinforced with straw. Polymer matrix composites commonly use thermoset or thermoplastic resins. Reinforcing fibres provide strength and stiffness, while the matrix offers rigidity and environmental protection. Fibres may be continuous, woven, or chopped, and their arrangement greatly affects composite properties. Continuous fibres are mainly used in structural applications, whereas short fibres are suitable for nonstructural applications and injection molding processes.

The main functions of fibers are:

- Carrying most of the load in structural composites.
- Providing stiffness, strength, and thermal stability.
- Offering electrical conductivity or insulation depending on fiber type.

The matrix material:

- Binds fibers together and transfer's load.
- Prevents crack propagation.
- Provides surface finish and shape.
- Protects fibers from chemical and mechanical damage.

Composite materials possess several advantages:

- High specific strength and stiffness.
- Excellent fatigue and corrosion resistance.
- Better vibration damping and dimensional stability.
- Greater design flexibility.
- Ability to produce complex near-net-shape components.
- Reduced assembly time and tooling costs.

These advantages make composites highly suitable for advanced engineering applications.

1.1 Carbon Fiber

Carbon fiber contains at least 92 wt% carbon and exhibits excellent tensile strength, low density, high thermal stability, good electrical conductivity, and superior creep resistance. It is mainly produced from polyacrylonitrile (PAN) or pitch. Carbon fibers are made by heating synthetic fibers in the absence of oxygen, resulting in highly aligned carbon crystals that provide exceptional strength-to-weight ratio.

The atomic structure of carbon fiber resembles graphite with graphene sheets arranged in a hexagonal pattern. Carbon fibers are widely used in composites in the form of woven fabrics, prepregs, continuous fibers, and chopped fibers. Manufacturing methods include filament winding, pultrusion, compression molding, and vacuum bagging.

Carbon fibers possess:

- High stiffness and tensile strength.
- Low weight and thermal expansion.
- Excellent chemical resistance and temperature tolerance.

Due to these properties, carbon fiber composites are extensively used in aerospace, military, construction, automotive, medical, and sporting industries. In automobiles, carbon fibers are used in body panels, suspension systems, and drive shafts to reduce weight and improve fuel efficiency. However, widespread automotive use is limited by high material cost and fabrication challenges.

1.2 Glass Fiber

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Glass fiber, or fiberglass, is made from extremely fine glass filaments. It is lightweight, strong, inexpensive, and less brittle than carbon fiber. Fiberglass has been used since the 1930s and can be easily molded into different shapes.

Glass fibers provide:

- High strength-to-weight ratio.
- Good thermal insulation.
- Excellent electrical insulation.
- Corrosion resistance and incombustibility.

Fiberglass does not rot and is resistant to insects and rodents. Because of its low thermal expansion and dielectric properties, it is widely used in insulation, electromagnetic windows, and structural applications.

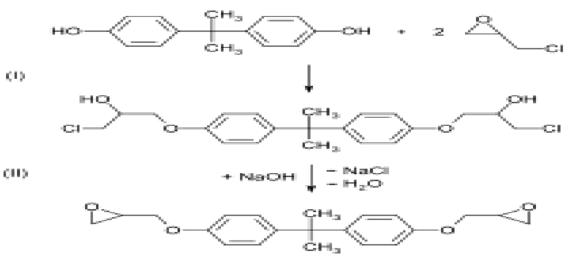
1.3 Epoxy Polymers

Epoxy polymers are widely used as matrix materials in fiber-reinforced composites and adhesives. They possess excellent adhesion, chemical resistance, mechanical strength, electrical insulation, and dimensional stability. Epoxies belong to the thermoset family and cannot be remelted after curing.

In aerospace and structural applications, epoxy resins are reinforced with fibers such as carbon, glass, Kevlar, and boron. The most common epoxy resin is diglycidyl ether of bisphenol A (DGEBA).

Figure 1 Epoxy Resin

Important properties of epoxy include:



- Strong adhesion to metals, wood, glass, and ceramics.
- High tensile and flexural strength.
- Good thermal and chemical resistance.
- Low shrinkage during curing.

However, cured epoxies are brittle and prone to crack growth. To improve toughness, a second phase such as rubber particles is introduced into the epoxy matrix. Rubber particles absorb energy and prevent crack propagation, thereby enhancing fracture toughness.

1.4 Rubber

Rubbers, or elastomers, are polymers capable of large reversible deformation due to the ability of their polymer chains to return to the original configuration after stress removal. Vulcanization introduces cross-links between chains to improve strength and durability.

Rubber products are widely used in tyres, hoses, conveyor belts, flooring, insulation materials, medical gloves, adhesives, and sporting goods. Vulcanized rubber is especially important in industrial and protective applications.

In rubber-toughened epoxy systems, toughness improves mainly through rubber cavitation and shear yielding.

Rubber particles absorb mechanical energy, reduce hydrostatic stress, and promote plastic deformation in the matrix. Additional mechanisms such as crack deflection, crack bridging, and microcracking also enhance toughness.

Uniformly dispersed rubber particles with strong interfacial bonding significantly improve impact resistance, whereas excessive rubber content can lead to agglomeration and reduced mechanical performance.

Objective

Present investigation is aimed at the development of rubber incorporated carbon fibre reinforced epoxy composites and rubber incorporated glass fibre reinforced epoxy composites and to make a comparitive study on the mechanical properties and chemical stability of these composites.

Scope of Investigation

- ❖ To prepare carbon fibre reinforced epoxy composites and glass fibre reinforced epoxy composites with incorporation of 5% rubber particles in both.
- ❖ Evaluation of mechanical properties such as tensile strength, tensile modulus, percentage tensile elongation, flexural strength, flexural modulus and analysis of chemical reactivity of these composites towards water, acid and base.
- ❖ To make a comparative study and find out the composition of the composite with enhanced properties.

2. METHODOLOGY

2.1MATERIALS SELECTION

2.1.1 REINFORCEMENT MATERIALS

Carbon Fibre Reinforced Polymer Composites (CFRP) are lightweight and high-strength materials widely used in everyday and engineering applications. CFRP is a fibre-reinforced composite in which carbon fibre acts as the main structural component. Carbon fibre is about five times stronger than steel, twice as stiff, and much lighter, making it suitable for manufacturing advanced components. The binding material is usually a thermoset resin such as epoxy, although polyester, vinyl ester, nylon, and other polymers may also be used. Epoxy rubber-based structural composites (ERCs) are especially important in aeronautical applications because of their excellent mechanical and thermal properties, along with their ability to provide multifunctional performance. Glass fibres are mainly produced from silica (SiO_2) sand, which melts at high temperatures. Rapid cooling of molten silica prevents crystallization and forms glass with an amorphous structure. Modern glass fibre production follows the same basic process developed in the 1930s, involving batching, melting, fiberization, coating, and drying/packaging.

In this project we have used carbon fibre and rubber particles as reinforcement materials on epoxy resin as matrix in sample-1 and glass fibre and rubber particles as reinforcement materials on epoxy resin as matrix in sample-1I

Bidirectional Carbon fibre - 6 layers – weight 20 gms per layer Glass fibre - 6 layers –weight 20 gms per layer

Natural Rubber material -24 mesh rubber

2.1.2 Matrix

Epoxy resin - 500 grams (grade 556)

Hardener - 50 grams (grade 951)

2.2 FABRICATION PROCESS

There are numerous methods for fabricating composite components. Composite fabrication processes typically involve some form of moulding, to shape the resin and reinforcement. A mould tool is required to give the unformed resin/fibre combination its shape prior to and during cure. The fabrication methodology of a composite depends mainly on three factors: (i) the characteristics of matrices and reinforcements,(ii) the shapes, sizes and engineering details of products, and (iii) end uses. The composite products are too many and cover a very wide domain of applications ranging from an engine valve to an aircraft wing. The fabrication technique varies from one product to the other. The different methods for fabrication are Vacuum bag moulding, Hand lay-up, Resin transfer mould, Compression moulding, Pultrusion etc.

VACUUM BAG MOULDING

Vacuum bag moulding is a modification of hand lay-up, in which the lay-up (necessarily smaller) is completed and placed inside a bag made of flexible film and all edges are sealed. The bag is then evacuated, so that the pressure eliminates voids in the laminate, forcing excess air and resin from the mould. By increasing external pressure, a higher glass concentration can be obtained, as well as better adhesion between the layers/plies of laminate. Some items for the process can be disposable.

2.3 FABRICATION PROCEDURE

A carbon fibre (CF) composite sample was prepared using six layers of carbon fibres weighing 20 g, while a glass fibre (GF) composite sample was fabricated using six layers of glass fibres weighing 20 g. In both cases, epoxy resin and rubber were mixed with curing agent in a ratio of 500:600 wt.%, and hardener was added to the epoxy resin in a 10:1 ratio. Mechanical stirring was used to ensure uniform mixing of rubber particles with the resin. Hardener grade 951 was added to increase the hardness of the epoxy resin. Since the gel time after hardener addition was about 30 minutes, the hand layup process was started immediately. Rectangular specimens of size 300 × 300 × 3 mm were fabricated using the hand layup method. Vacuum bagging was carried out at a pressure range of 650–675 Hg/mm^2 with continuous air suction using a vacuum pump. The specimens were then post-cured by keeping them under atmospheric conditions for 5–6 hours, followed by oven curing at 100°C for 60 minutes.

3. EXPERIMENTAL ANALYSIS

TESTING DETAIL

The mechanical properties like ultimate tensile strength, tensile modulus, flexural strength, flexural modulus and chemical stability towards water, acids and bases were evaluated for the carbon fibre reinforced epoxy composites with 5% rubber and glass fibre reinforced epoxy composites with 5% rubber.

UTM MACHINE

A Universal Testing Machine (UTM) was used to determine the tensile stress and compressive strength of hybrid composite materials. The machine can perform standard tensile and compression tests on various materials and structures. Tensile tests were carried out on unidirectional composites using straight-sided specimens fitted with fibre glass tabs and clamped in the UTM. During the test, the specimen was subjected to controlled tensile load until fracture occurred. The test measured properties such as ultimate tensile strength, breaking strength, maximum elongation, and reduction in area. Mechanical properties including Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics were also determined.

3.1 TENSILE TEST

A tensile specimen is a standardized sample used for tensile testing. It consists of two shoulders and a smaller gauge section between them, where deformation and fracture occur. The larger shoulders allow the specimen to be firmly gripped during testing. Specimen shoulders can be designed in different forms to suit various gripping systems. Serrated grips are simple and inexpensive but depend on proper alignment by the technician. Pinned grips provide better alignment, while threaded grips also ensure accurate alignment if properly tightened to avoid thread stripping before fracture. In large castings and forgings, extra material is often added so that test specimens can be prepared from it. However, these specimens may not exactly represent the entire workpiece because the grain structure can vary.

3.2 FLEXURAL STRENGTH

Flexural strength, also called modulus of rupture or bend strength, is the ability of a brittle material to resist deformation under load. It is commonly measured using a three-point bending test, where a specimen with circular or rectangular cross-section is bent until fracture occurs. The maximum stress developed at the point of fracture is known as the flexural strength.

During bending, the inner surface of the material experiences compressive stress, while the outer surface experiences tensile stress. Since most materials fail under tensile stress before compressive stress, the maximum tensile stress sustained before fracture determines the flexural strength. The outermost regions subjected to maximum stress are called the "extreme fibers.

3.3 WATER, ACID, AND BASE TEST

Water absorption is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments. For the water absorption test, the specimens are dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then dipped in water for 12 hours. Specimens are taken, dried with a lint free cloth and weighed.

Water absorption is used to determine the amount of water absorbed under specified conditions. Water absorption is expressed as increase in weight percent.

$$\text{Percent Change by Water Absorption (PCW)} = \frac{(\text{wet weight}) - (\text{dry weight})}{(\text{dry weight})} \times 100$$

For acid test, the specimens are dried in an oven for a specified time and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then dipped in hydrochloric acid for 12 hours. Specimens are taken out, dried with a lint free cloth, and weighed. Weight loss due to corrosion is calculated.

$$\text{Percent Change by Acid corrosion (PCA)} = \frac{(\text{dry weight}) - (\text{weight after corrosion})}{(\text{dry weight})} \times 100$$

For alkaline test, the specimens are dried in an oven for a specified time and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then dipped in sodium hydroxide for 12 hours. Specimens are taken out, dried with a lint free cloth, and weighed. Weight change due to alkaline action is calculated.

$$\text{Percent Change by Base (PCB)} = \frac{(\text{dry weight}) - (\text{weight after dip in base})}{(\text{dry weight})} \times 100$$

4. RESULTS AND DISCUSSION

In the present work, properties of carbon reinforced epoxy composites and glass reinforced epoxy composites with 5 % rubber particles are compared to establish the extent of utility. The total percentage of carbon fibre is 20, percentage of rubber particles is 5 and balance is epoxy matrix (75%) in the **Sample-I** and the total percentage of glass fibre is 20, percentage of rubber is 5 and balance is epoxy matrix (75%) in the **Sample-II**. Properties studied are Tensile strength, Tensile modulus, % of elongation, Flexural strength, and Flexural modulus.

Sample-I and Sample-II are prepared and the mechanical properties like Tensile strength, Tensile modulus, % of elongation, Flexural strength, and Flexural modulus are determined.

4.1 Tensile Strength

Tensile strength is the amount of load or stress that can be handled by a material before it stretches and breaks. As its name implies, tensile strength is the material's resistance to tension that is caused by mechanical loads applied to the material. The ability to resist breaking under tensile stress is one of the most important and widely measured properties of materials used for structural applications. The tensile strength is the maximum tensile stress that a material can be subjected to before failure, although the actual definition of failure usually varies according to the material's type and design.

Tensile Properties	Sample-I	Sample-II
Area	67.60 mm^2	52.21 mm^2
Width	23.07 mm	24.86 mm
Thickness	2.93 mm	2.10 mm
Ultimate Load (Fm)	30390.000 N	9280.000 N
Displacement at Fm	10.51 mm	6.11 mm
Max Displacement	10.94 mm	7.17 mm
Tensile Strength	449.589 Mpa	177.757 Mpa
Tensile Modulus	431.886 Mpa	151.468 Mpa
% Tensile elongation	4.09%	17.35%

Table 1 Tensile Strength

Tensile Strength is calculated using the following formula

$$\text{Tensile Strength} = \frac{\textit{Load}}{\textit{Area}}$$

Sample-I

$$\text{Tensile Strength} = \frac{30390}{67.60} = 449.589 \text{ Mpa}$$

Sample-II

$$\text{Tensile Strength} = \frac{9280}{52.21} = 177.757 \text{ Mpa}$$

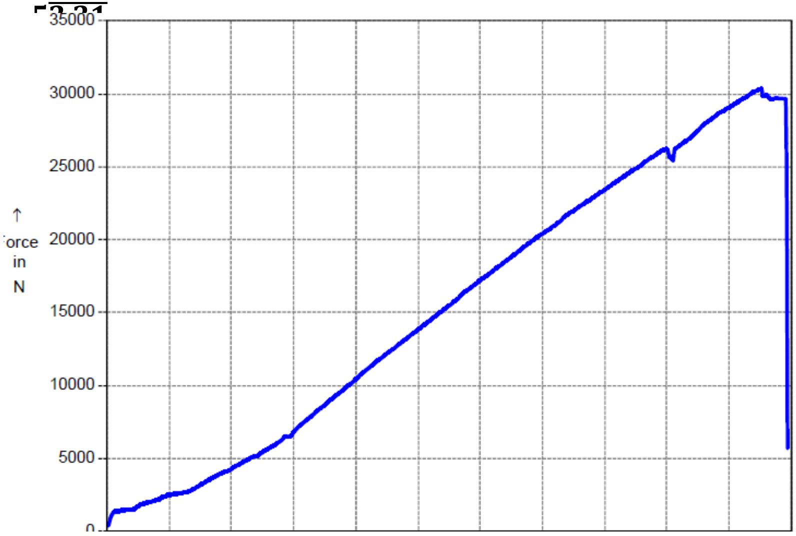


Figure 1: Tensile graph of Sample-I

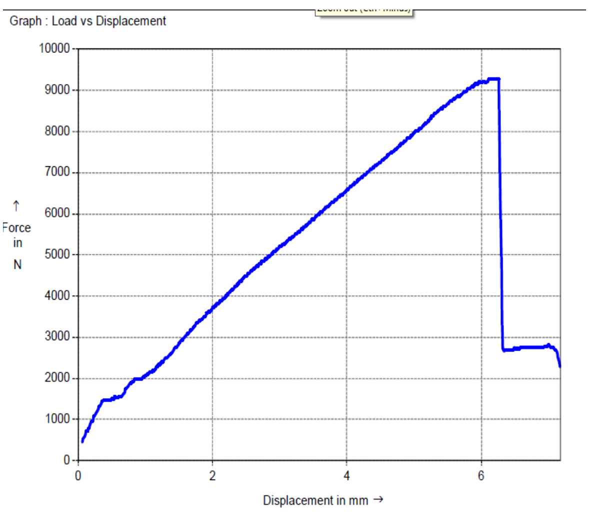


Figure 2: Tensile graph of Sample-II

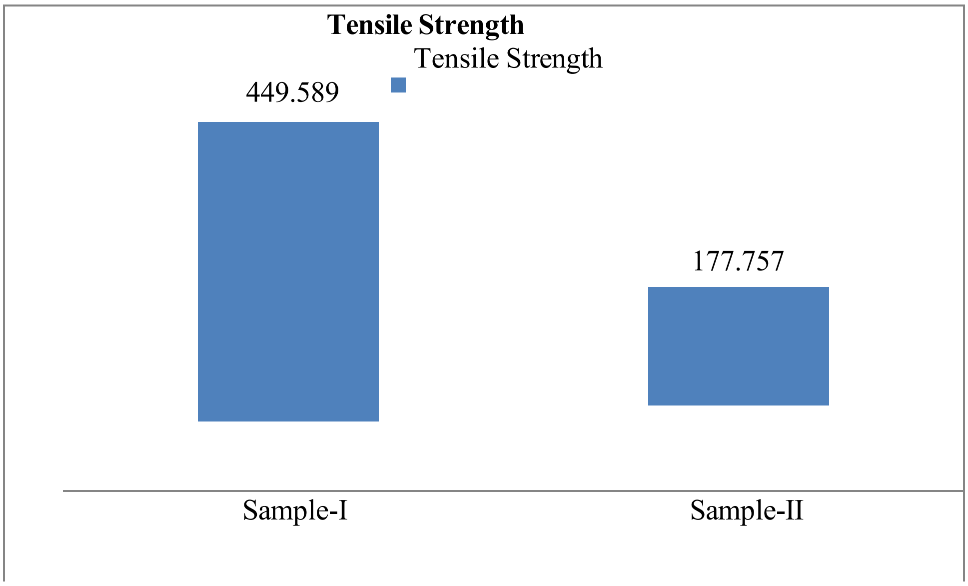


Figure 3: Comparison of Tensile Strength

When the tensile strengths of Sample-I and Sample-II were compared, Sample-I showed higher tensile strength. This improvement is mainly due to the presence of rubber particles in Sample-I, which enhanced the toughness of the composite more effectively than the glass reinforced epoxy composite in Sample-II.

The toughening effect of rubber particles in brittle epoxy matrices occurs mainly through rubber cavitation followed by shear yielding. Under tensile stress, small voids are formed inside the rubber particles. This reduces hydrostatic stress in the material and changes the stress condition from triaxial to uniaxial tension, which promotes the formation of shear bands in the matrix.

Rubber particles therefore help absorb energy by initiating ductile shear deformation. The interaction between stress fields and rubber particles creates deformation zones around the particles, improving toughness. A higher number of rubber particles produces more deformation zones before fracture occurs.

Small micrometer-sized rubber particles are especially effective in improving shear yielding and plastic deformation of the epoxy matrix. Microscopic studies showed that rubber particles elongate along with the matrix near the crack tip. Internal cavitation of rubber particles reduces strain constraints and allows sufficient stress for shear yielding, thereby increasing the tensile strength and toughness of the composite.

4.2. Tensile Modulus

Tensile modulus, also known as Young's modulus, is a measure of a materials flexibility along an axis of strain, which is not normalized for thickness. The stress strain data is collected from a sample place under tensile loading. Young's modulus measures a material's resistance to elastic (recoverable) deformation under load. A stiff material has a high Young's modulus and changes its shape only slightly under elastic loads (e.g. diamond). A flexible material has a low Young's modulus and changes its shape considerably (e.g. rubbers).

$$\text{Tensile Modulus} = \frac{Load \times Displacement}{}$$

$Area \times Max.displacement$

Sample-I

$$\text{Tensile Modulus} = \frac{30390 \times 10.51}{67.6 \times 10.94} = 431.886$$

Sample-II

$$\text{Tensile Modulus} = \frac{9280 \times 6.11}{52.21 \times 7.17} = 151.468$$

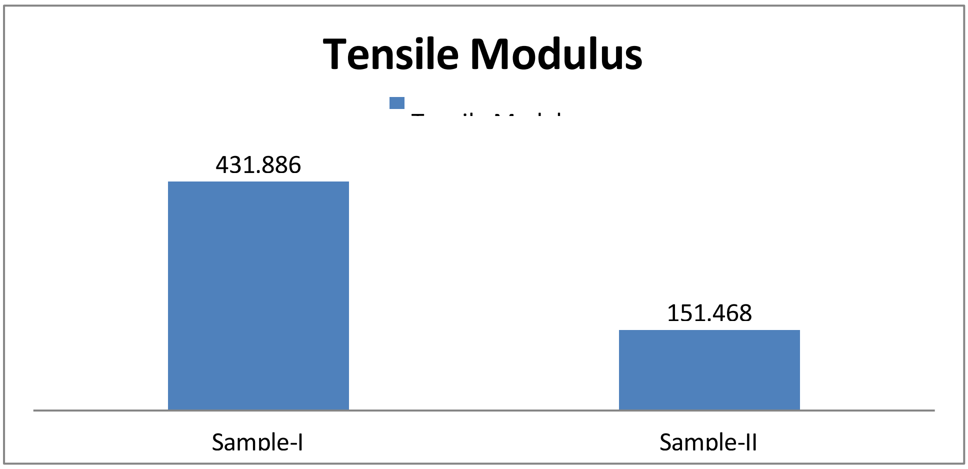


Figure 4 Comparison of Tensile Modulus

The Tensile modulus of Sample I is higher than that of Sample II. Tensile modulus evaluates the elasticity of a material, which is the relation between the deformation of a material and the power needed to deform it.

4.3. Percentage Tensile Elongation

The **"**percentage elongation" is a mechanical property that represents the material's ductility, i.e., the ability of the material to be plastically (permanently) deformed under tension. Materials with high percent elongation are described as "ductile," while those with low percent elongation are described as "brittle".

$$\text{Percentage Tensile Elongation} = \frac{Max\text{-}displacement - Displacement}{Displacement} \times 100$$

Sample-I

$$\text{Percentage Tensile Elongation} = \frac{10.94 - 10.51}{10.51} \times 100 = 4.09\ \%$$

Sample-II

$$\text{Percentage Tensile Elongation} = \frac{7.17 - 6.11}{6.11} \times 100 = 17.35\ \%$$

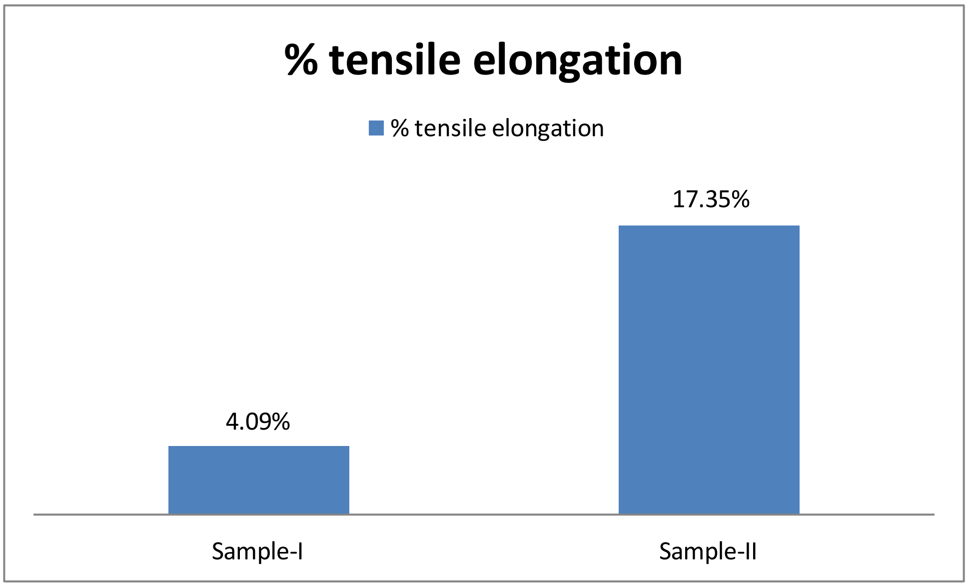


Figure 5: Comparison of Percentage Tensile Elongation

4.4. Flexural Strength

Flexural Properties	Sample-I	Sample-II
Area	40.83 mm²	24.65 mm²
Width	13.70 mm	13.25 mm
Thickness	2.98 mm	1.86 mm
Ultimate Load (Fm)	420.000 N	150.000 N
Displacement at Fm	5.17 mm	3.70 mm
Max Displacement	12.70 mm	9.90 mm
Flexural Strength	10.288 Mpa	6.086 Mpa
Flexurul Modulus	4.187 Mpa	2.274 Mpa

Flexural Strength is calculated as follows

$$\text{Flexural Strength} = \frac{Load}{Area}$$

Sample-I

$$\text{Flexural Strength} = \frac{420}{40.83} = 10.288 \text{ Mpa}$$

Sample-II

$$\text{Flexural Strength} = \frac{150}{24.65} = 6.086 \text{ Mpa}$$

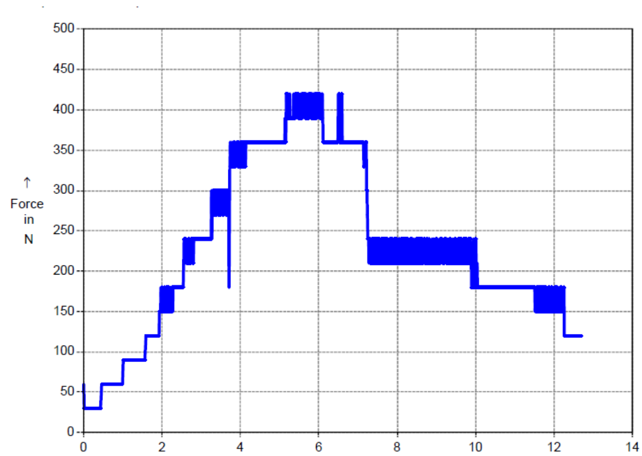


Figure 6: Flexural Strength curve of Sample-I

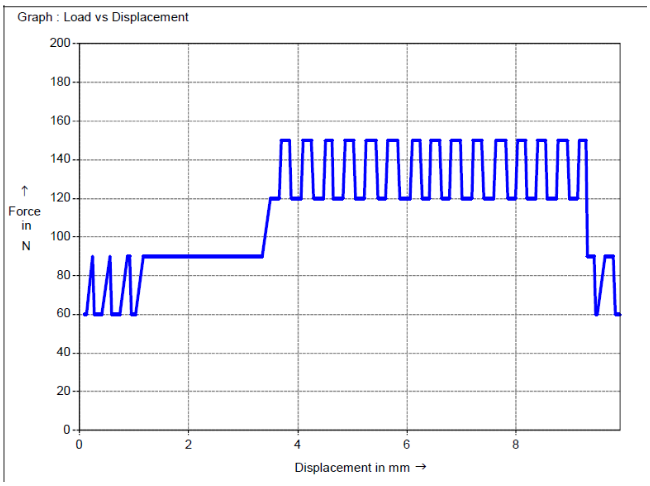


Figure 7: Flexural Strength curve of Sample-II

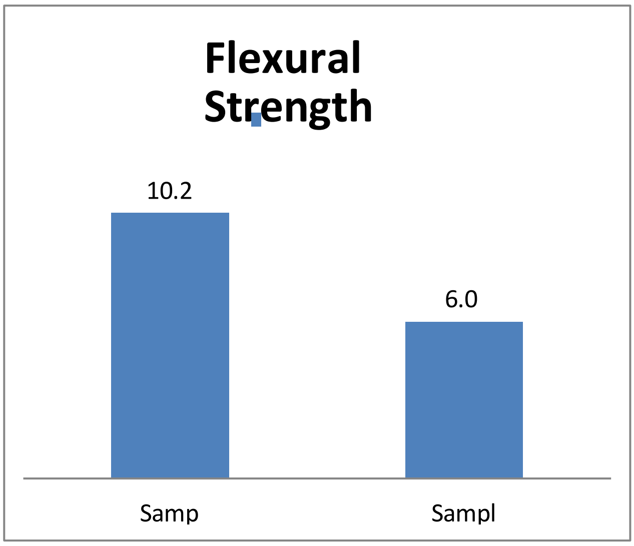


Figure 8: Comparison of Percentage Flexural Strength

4.5. Flexural Modulus

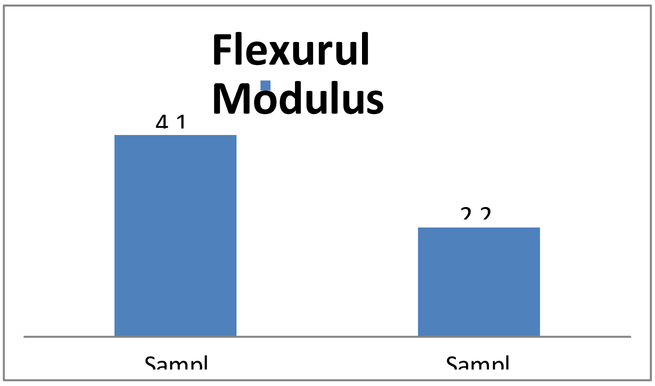
$$\text{Flexural Modulus} = \frac{Load \times Displacement}{Area \times Max.displacement}$$

Sample-I

$$\text{Flexural Modulus} = \frac{420 \times 5.17}{40.83 \times 12.7} = 4.187$$

Sample-II

$$\text{Flexural Modulus} = \frac{150 \times 3.70}{24.65 \times 9.90} = 2.274$$



N Figure 9: Comparison of Percentage Flexural modulus

The flexural modulus is inversely related to deflection - a lower deflection would result in a higher modulus. So a higher flexural modulus material is 'stiffer' than a lower flexural modulus material.Hence rubber incorporated carbon reinforced epoxy composite is more stiffer than glass reinforced epoxy composite.

4.6. Water, Acid, And Base Test

SAMPLE	WATER [gm]	HYDROCHLORIC ACID [gm]	SODIUM HYDROXIDE [gm]
SAMPLE-I	3.5	3.5	3.5
SAMPLE-II	3.8	3.8	3.8

$$\text{Percent Change by Water Absorption} = \frac{(\text{wet weight}) - (\text{dry weight})}{(\text{dry weight})} \times 100$$

Sample-I

$$\text{PCW} = \frac{3.5 - 3.5}{3.5} \times (100) = 0\ \%$$

Sample-II

$$PCW = \frac{3.8 - 3.8}{3.8} \times (100) = 0\ \%$$

$$\text{Percent Change by Acid corrosion (PCA)} = \frac{(\text{dry weight}) - (\text{weight after corrosion})}{(\text{dry weight})} \times 100$$

Sample-I

$$PCA = \frac{3.5 - 3.5}{3.5} \times (100) = 0\ \%$$

Sample-II

$$PCA = \frac{3.8 - 3.8}{3.8} \times (100) = 0\ \%$$

$$\text{Percent Change by Base (PCB)} = \frac{(\text{dry weight}) - (\text{weight after dip in base})}{(\text{dry weight})} \times 100$$

Sample-I

$$PCB = \frac{3.5 - 3.5}{3.5} \times (100) = 0\ \%$$

Sample-II

$$PCB = \frac{3.8 - 3.8}{3.8} \times (100) = 0\ \%$$

Both Sample-I and Sample-II are not affected by water, acid and base. This chemical stability towards water, acid and base is very significant in making many constructive materials.

5. CONCLUSION

- Investigation of the mechanical properties like Tensile strength, Tensile modulus, Flexural strength and Flexural modulus of the newly developed carbon reinforced epoxy composites and glass reinforced epoxy composites with 5% Rubber incorporation shows carbon reinforced epoxy composites with 5% Rubber has greater enhanced mechanical properties than glass reinforced epoxy composites with 5% Rubber.
- Analysis of the reactivity of the carbon reinforced epoxy composites with 5% Rubber and glass reinforced epoxy composites 5% Rubber towards water, acid and base shows, there is no change in weight thereby indicating a greater chemical stability in both the cases.
- Sample-I is more brittle in nature because the value of % Tensile elongation is low whereas Sample-II is more ductile.

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