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**Investigation on the Mechanical Behaviour and Chemical Stability of Rubber Incorporated Carbon Fiber Reinforced Epoxy Composites**

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**Abstract**

Carbon fiber-reinforced epoxy composites are widely utilized in aerospace, automotive, and marine engineering due to their high strength-to-weight ratio and corrosion resistance. However, their inherent brittleness often limits their energy absorption capabilities. This study focuses on developing and comparatively evaluating rubber-incorporated carbon fiber-reinforced epoxy composites to enhance fracture toughness without significantly compromising structural integrity. Two distinct formulations featuring 10% and 15% rubber particle weight fractions were developed. The composites were fabricated using a combination of hand lay-up and vacuum bag molding techniques, utilizing mechanical stirring to ensure uniform dispersion of the rubber particles within the epoxy matrix prior to curing. Mechanical properties were systematically evaluated using a Universal Testing Machine (UTM) in accordance with ASTM standards, while chemical durability was assessed via immersion in water, hydrochloric acid (HCl), and sodium hydroxide (NaOH) solutions. Experimental results revealed that the composite containing 10% rubber content exhibited superior mechanical performance compared to the 15% formulation, achieving a tensile strength of 654.16 MPa, a tensile modulus of 646.47 MPa, a flexural strength of 11.78 MPa, and a flexural modulus of 5.36 MPa. Furthermore, both formulations demonstrated exceptional environmental stability, exhibiting no measurable weight loss across all corrosive media. The study concludes that optimizing rubber incorporation at 10% successfully balances enhanced toughness with high mechanical and chemical stability, offering a highly viable material solution for demanding structural applications.

**Keywords:** Carbon Fiber Reinforced Composites, Epoxy Resin, Rubber Toughening, Mechanical Properties, Chemical Stability.

## I. INTRODUCTION

### 1. Composites

Composite materials have been used for many years in engineering applications, but their industrial importance increased significantly during the 1960s with the development of polymer-based composites. Today, composites are widely used in aerospace, automotive, marine, sports, consumer goods, and oil industries due to their lightweight nature and high performance. Compared to conventional materials such as steel and aluminum, composites offer higher strength-to-weight ratio and improved efficiency. Replacing steel with composites can reduce weight by 60–80%, while replacing aluminum can reduce weight by 20–50%.

A composite material is formed by combining two or more materials to achieve properties superior to those of the individual components. In fiber-reinforced composites, the fibers and matrix remain separate at the molecular level but function together as a single system. Natural examples of composites include wood and marine shells, while traditional clay mixed with straw also represents an early composite material.

Polymer matrix composites are among the most commonly used composite systems and may contain thermosetting or thermoplastic resins. Reinforcing fibers provide strength and stiffness, while the matrix binds the fibers, transfers load, and protects them from environmental damage. Fibers may be continuous, woven, chopped, or arranged in mats depending on the application. Continuous fibers are preferred for structural applications, whereas short fibers are mainly used in molding and nonstructural applications.

The combined action of fibers and matrix gives composites excellent mechanical and environmental properties. Composites possess high specific strength and stiffness, good fatigue and corrosion resistance, superior vibration damping, and greater design flexibility. Their lightweight nature improves fuel efficiency in automobiles and aircraft, making them highly suitable for aerospace, transportation, and sports applications.

### 1.1 Carbon Fiber

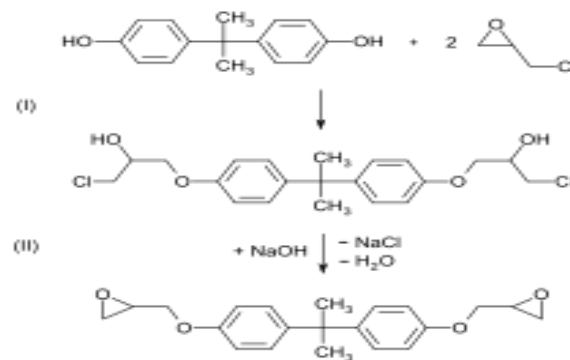
Carbon fiber is an important reinforcing material widely used in advanced composites. Fibers containing at least 92 wt% carbon are called carbon fibers, while those with more than 99 wt% carbon are known as graphite fibers. Carbon fibers possess high tensile strength, low density, excellent thermal stability, chemical resistance, and good electrical conductivity. They are

mainly produced from polyacrylonitrile (PAN) or pitch precursors through controlled heating in the absence of oxygen, which aligns carbon atoms parallel to the fiber axis and provides a very high strength-to-weight ratio.

The structure of carbon fiber is similar to graphite, with carbon atoms arranged in hexagonal layers. Carbon fibers are available as woven fabrics, prepregs, continuous fibers, and chopped fibers. Composite fabrication methods include filament winding, pultrusion, compression molding, and vacuum bagging. Due to their high stiffness, low thermal expansion, temperature resistance, and lightweight nature, carbon fiber composites are widely used in aerospace, military, automotive, construction, and sporting applications. However, their wider use is limited by high production cost and fabrication complexity.

### 1.2 Epoxy Polymers

Epoxy polymers are widely used as matrix materials in fiber-reinforced composites because of their excellent adhesion, chemical resistance, mechanical strength, and electrical insulating properties. Epoxy resins belong to the thermosetting family of polymers and cannot be remelted after curing. One of the most commonly used epoxy resins is diglycidyl ether of bisphenol A (DGEBA).



**Figure 1 Epoxy Resin**

Epoxy matrices are widely used in aerospace and structural applications with reinforcements such as carbon fiber, glass fiber, Kevlar, and boron fibers. Epoxy materials show strong adhesion to metals, ceramics, wood, glass, and concrete, along with high tensile and flexural strength, low curing shrinkage, good dimensional stability, and excellent chemical and moisture resistance. However, cured epoxy systems are brittle and prone to crack propagation. To improve fracture toughness and impact resistance, rubber particles are added to the epoxy matrix. Rubber toughening increases energy absorption and reduces crack growth in the composite structure.

### 1.3 Rubber

Rubber materials, or elastomers, are polymers capable of large reversible deformation due to the ability of polymer chains to return to their original configuration after stress removal. Vulcanization forms cross-links between polymer chains, improving strength, elasticity, and durability. Rubber products are widely used in tires, conveyor belts, hoses, flooring, medical gloves, adhesives, sports equipment, and insulation materials.

Adding rubber particles to epoxy matrices is an effective way to improve toughness. The toughening mechanism mainly involves rubber cavitation and shear yielding, where rubber particles absorb mechanical energy and promote localized plastic deformation in the brittle epoxy matrix. Other mechanisms such as crack deflection, crack bridging, crack pinning, and microcracking also enhance fracture resistance. Well-dispersed rubber particles with strong interfacial bonding improve toughness and impact resistance, while excessive rubber content may cause particle agglomeration and reduced mechanical performance.

#### Objective

Present investigation is aimed at the development of rubber incorporated carbon fibre reinforced epoxy composites with varied composition of Rubber and to make a comparative study on the mechanical properties and chemical stability of these composites.

#### Scope of Investigation

- ❖ To prepare carbon fibre reinforced epoxy composites with incorporation of 10% and 15%rubber particles.
- ❖ Evaluation of mechanical properties such as tensile strength, tensile modulus, percentage tensile elongation, flexural strength, flexural modulus and analysis of chemical reactivityof 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

### 2.1 MATERIALS SELECTION

#### 2.1.1 REINFORCEMENT MATERIALS

Carbon Fiber Reinforced Polymer Composites (CFRP) are lightweight and high-strength materials widely used in many everyday and engineering applications. CFRP refers to fibre-reinforced composites in which carbon fibre serves as the main structural component. Carbon fibre is about five times stronger and twice as stiff as steel, while being much lighter, making it an ideal material for advanced manufacturing applications. The binding material is usually a thermoset resin such as epoxy, although polyester, vinyl ester, nylon, and other thermoset or thermoplastic polymers may also be used. Epoxy rubber-based structural composites (ERCs) are especially important in aeronautical engineering because they provide good mechanical and thermal performance along with multifunctional properties.

In this project we have used carbon fibre and rubber particles as reinforcement materials on epoxy resin as matrix.

Bidirectional Carbon 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 molding is a modification of hand lay-up in which the lay-up (necessarily smaller) is completed, 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 the laminate. Some items for the process can be disposable

### **2.3 FABRICATION PROCEDURE**

A sample of carbon fibre (CF) was prepared using 6 layer of carbon fibres. The carbon fibres have a weight of 20gms. The predetermined epoxy resin and rubber were mixed with curing agent at a ratio of 500:600 wt. %. The hardener was added to the epoxy resin in the ratio of 10:1. The mechanical stirring process was used to mix the rubber particles with resin particles in correct ratio. The hardener grade 951 was added to the epoxy resin. This was added to increase the hardness of the epoxy resin. Since the gel time for a resin after mixing of hardener is 30 minutes, the hand layup process was started immediately. Rectangular specimen with 300\*300\*3 mm were made using hand layup process.

The vacuum bag process was done at the pressure range of 650-675 Hg/mm<sup>2</sup>. Air was sucked continuously with the help of a sucking pump. The final process was a post-curing process. The specimen was placed in an atmospheric condition for 5-6 hours. The specimen was placed in the oven for the time period for 60 minutes. The temperature was maintained in the oven for 100<sup>0</sup>C. That temperature was maintained till the end of the process.

## **3. EXPERIMENTAL ANALYSIS**

### **3.1 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 10 % rubber and 15% rubber.

### **3.2 UTM MACHINE**

A Universal Testing Machine (UTM) was used to evaluate the tensile stress and compressive strength of hybrid composite materials. The machine can perform standard tensile and compression tests on materials, components, and structures. Tensile tests were carried out on

unidirectional composites using straight-sided specimens fitted with fibre glass tabs and clamped in the testing machine. Streamlined or reduced-section specimens can also be used. In tensile testing, the specimen is subjected to controlled tensile force until fracture occurs. The test directly measures ultimate tensile strength, breaking strength, maximum elongation, and reduction in area. Additional properties such as Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics can also be determined. Uniaxial tensile testing is commonly used for evaluating isotropic materials. The tensile test was conducted according to ASTM A378:2017 standards. The specimen was fixed between adjustable grips of a computerized UTM at room temperature, and load was applied until fracture. Maximum load and elongation values were recorded during the experiment.

### **3.3 TENSILE TEST**

A tensile specimen is a standardized sample used for tensile testing. It consists of two large shoulders for gripping and a smaller gauge section where deformation and fracture occur. Specimens may have round or flat cross-sections with threaded or serrated grip designs. Different gripping systems provide different advantages. Serrated grips are simple and inexpensive but depend on proper alignment by the technician, whereas pinned and threaded grips provide better alignment. However, threaded grips must be properly tightened to prevent 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 fully represent the workpiece due to variations in grain structure.

### **3.4 FLEXURAL STRENGTH**

Flexural strength, also called modulus of rupture, bend strength, or fracture 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 experienced at the point of fracture is known as the flexural strength.

During bending, the inner surface of the specimen experiences maximum compressive stress, while the outer surface experiences maximum tensile stress. Since most materials fail under tensile stress before compressive stress, the maximum tensile stress sustained before fracture determines the flexural strength. These highly stressed inner and outer regions are called the "extreme fibers."

### **3.5 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 an increase in weight percent.

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

For an 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 the 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 with 10 % and 15 % rubber particles are compared to establish the extent of utility. The total percentage of fibre is 15, percentage of rubber particles is 10 and balance is epoxy matrix (75%) in the **Sample-I** and the total percentage of fibre is 10, percentage of rubber particles is 15 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 maximum load or stress a material can withstand 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	46.41 mm <sup>2</sup>	82.01mm <sup>2</sup>
Width	23.44 mm	23.77mm
Thickness	1.98 mm	3.45 mm
Ultimate Load (Fm)	30360.000 N	28950.000 N
Displacement at Fm	9.23 mm	9.70 mm
Max Displacement	9.34 mm	9.77 mm
Tensile Strength	654.155 Mpa	353.019 Mpa
Tensile Modulus	646.465 Mpa	350.476
% Tensile elongation	1.19%	1%

**Table 4.1 Tensile Strength**

Tensile Strength is calculated using the following formula

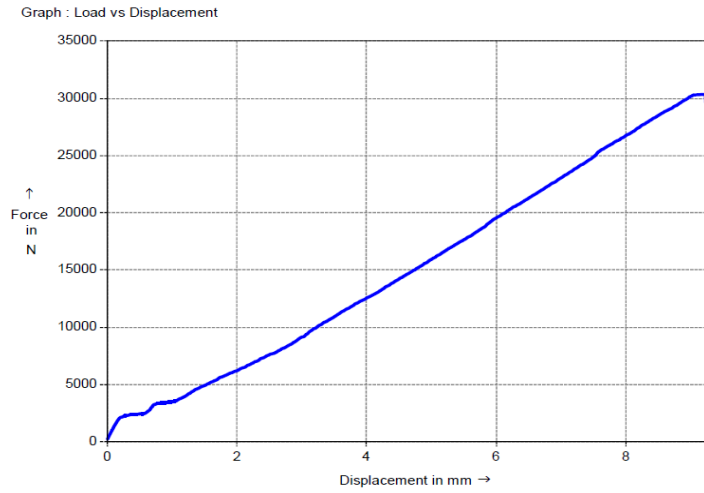
$$\text{Tensile Strength} = \frac{\text{Load}}{\text{Area}}$$

**Sample-I**

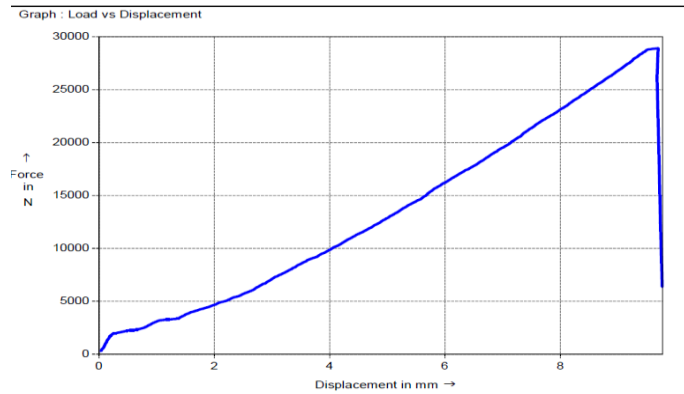
$$\text{Tensile Strength} = \frac{30360}{46.41} = 654.155 \text{Mpa}$$

**Sample-II**

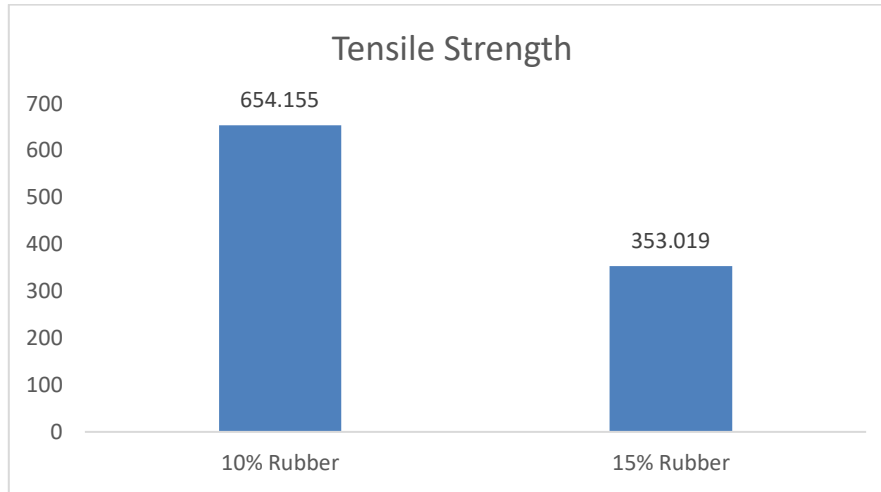
$$\text{Tensile Strength} = \frac{28950}{82.01} = 353.006 \text{ Mpa}$$



**Figure 1 Tensile graph of Sample-I**



**Figure 2 Tensile graph of Sample-II**



**Figure 3 Comparison of Tensile Strength**

On comparing the tensile strengths of Sample-I and Sample-II, Sample-I showed higher tensile strength, even though the rubber particle content in Sample-I was 5% lower than in Sample-II. The toughening effect of rubber particles in brittle epoxy matrices has been explained by several theories. The main energy absorption mechanism in rubber-toughened epoxy systems is rubber cavitation followed by shear yielding. Under triaxial tensile stress, voids form inside the rubber particles. Once cavitation occurs, hydrostatic tension in the material is relieved, and the stress state changes from triaxial to uniaxial tension, which promotes the formation of shear bands. Rubber particles therefore initiate ductile shear yielding by reducing hydrostatic stress. Shear bands or deformation zones develop due to interaction between crack-tip stress fields and rubber particles, creating stress concentration in the surrounding matrix. Toughness improvement increases with the number of rubber particles because more deformation zones are formed before fracture. Small micrometer-sized rubber particles are highly effective in promoting shear yielding and plastic deformation in the brittle epoxy matrix. Microscopic studies show that rubber particles elongate along with the matrix near the crack tip. Internal cavitation reduces plane strain constraint and bulk modulus, producing sufficient deviatoric stress for shear yielding and improved toughness.

#### **4.2 Tensile Modulus**

Tensile modulus, also known as Young's modulus, is a measure of a material's flexibility along an axis of strain, which is not normalized for thickness. The stress-strain data is collected from a sample placed under tensile loading. Young's modulus measures the resistance of a material 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).

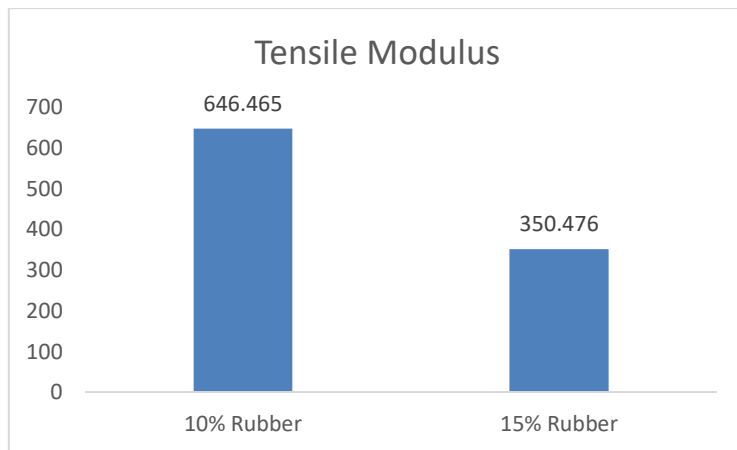
$$\text{Tensile Modulus} = \frac{\text{Load} \times \text{Displacement}}{\text{Area} \times \text{Max. displacement}}$$

**Sample-I**

$$\text{Tensile Modulus} = \frac{30360 \times 9.23}{46.41 \times 9.34} = 646.465$$

**Sample-II**

$$\text{Tensile Modulus} = \frac{28950 \times 9.70}{82.01 \times 9.77} = 350.476$$



**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 force 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 of low percent elongation are described as “brittle”.

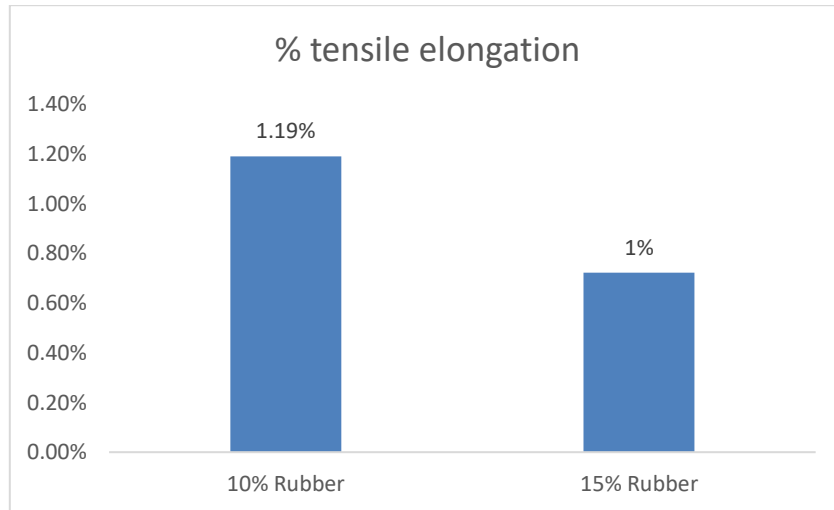
$$\text{Percentage Tensile Elongation} = \frac{\text{Max. displacement} - \text{Displacement}}{\text{Displacement}} \times 100$$

**Sample-I**

$$\text{Percentage Tensile Elongation} = \frac{9.34 - 9.23}{9.23} \times 100 = 1.19 \%$$

**Sample-II**

$$\text{Percentage Tensile Elongation} = \frac{9.77 - 9.70}{9.70} \times 100 = 1.00 \%$$



**Figure 5 Comparison of Percentage Tensile Elongation**

**4.4 Flexural Strength**

Flexural Properties	Sample-I	Sample-II
Area	35.66 mm <sup>2</sup>	44.05 mm <sup>2</sup>
Width	12.34 mm	12.48 mm
Thickness	2.89 mm	3.53 mm
Ultimate Load (F <sub>m</sub> )	420.000 N	450.000 N
Displacement at F <sub>m</sub>	6.46 mm	4.62 mm
Max Displacement	14.20 mm	10.29 mm
Flexural Strength	11.777 Mpa	10.215 Mpa
Flexural Modulus	5.358 Mpa	4.586 Mpa

Flexural Strength is calculated as follows

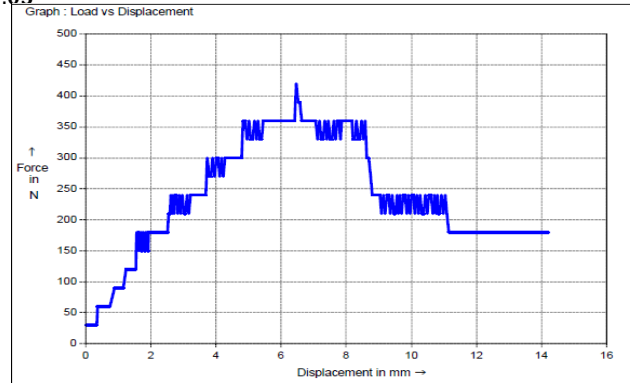
$$\text{Flexural Strength} = \frac{\text{Load}}{\text{Area}}$$

**Sample-I**

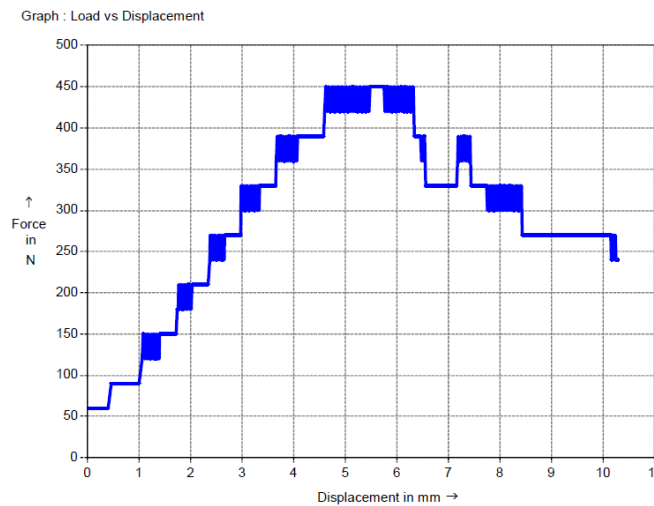
$$\text{Flexural Strength} = \frac{420}{35.66} = 11.777 \text{ Mpa}$$

**Sample-II**

$$\text{Flexural Strength} = \frac{450}{44.05} = 10.215 \text{ Mpa}$$



**Figure 6 Flexural Strength curve of Sample-I**



**Figure 7 Flexural Strength curve of Sample-II**

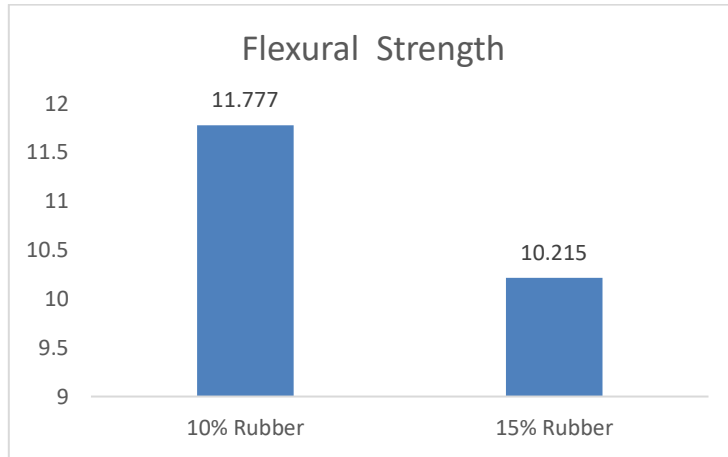


Figure 8 Comparison of Percentage Flexural Strength

**4.5. Flexural Modulus**

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

**Sample-I**

$$\text{Flexural Modulus} = \frac{420 \times 6.46}{35.66 \times 14.2} = 5.358$$

**Sample-II**

$$\text{Flexural Modulus} = \frac{450 \times 4.62}{44.05 \times 10.29} = 4.586$$

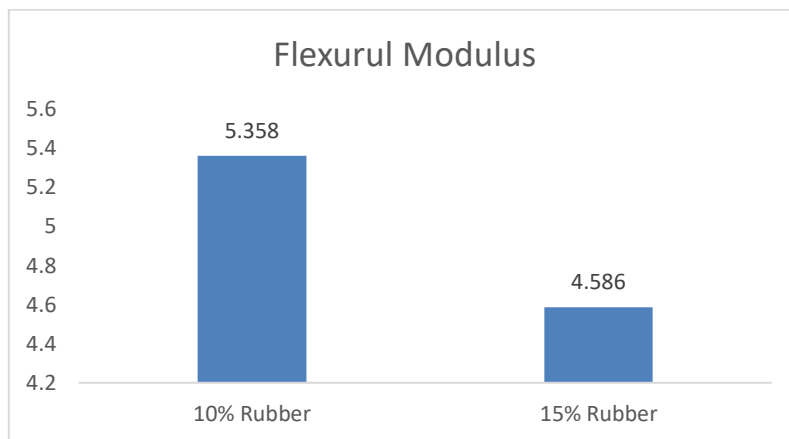


Figure 9 Comparison of Percentage Flexural modulus

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

**4.6 WATER, ACID AND BASE TEST**

SAMPLE	WATER [gm]	HYDROCHLORIC ACID [gm]	SODIUM HYDROXIDE [gm]
SAMPLE-I	3.6	3.6	3.6
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**

$$\text{PCW} = \frac{3.6 - 3.6}{3.6} \times (100) = 0 \%$$

**Sample-II**

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

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

**Sample-I**

$$\text{PCA} = \frac{3.6 - 3.6}{3.6} \times (100) = 0 \%$$

**Sample-II**

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

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

**Sample-I**

$$\text{PCB} = \frac{3.6 - 3.6}{3.6} \times (100) = 0 \%$$

**Sample-II**

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

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

**CONCLUSION**

- ❖ Investigation of the mechanical properties like Tensile strength, Tensile modulus, Flexural strength and Flexural modulus of the newly developed epoxy composites with 10% and 15% Rubber incorporation shows epoxy composites with 10% Rubber has greater enhanced mechanical properties than epoxy composites with 15% Rubber.
- ❖ Analysis of the reactivity of the epoxy composites with 10% Rubber and 15% Rubber towards water, acid and base shows there is no change in weight thereby indicating a greater chemical stability in both the cases.

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