Evaluation of Mechanical Properties of Graphene Polymer Matrix Composites for an Unmanned Aerial Vehicle(UAV)

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ABSTRACT

Composite materials are widely used in aerospace and other fields, mainly due to their light weight, high strength to weight ratio, chemical resistance and high fatigue life of the different types of composites. Polymer matrix composites find extensive applications in aerospace industries. Currently fiber reinforced polymer matrix composites constitute more than 90% of the total composite used in aerospace industry. The abundant use of composites in aerospace filed has motivated the authors to take up an experimental work to figure out the necessary mechanical properties of a new Polymer Matrix Composite (PMC). The method of manufacturing a PMC has used commercially available epoxy resin systems. PMC is one of the key survival materials in aerospace products whether it is for civil or military use. In the current work an attempt has been made for a low cost manufacturing method. An Unmanned Aerial Vehicle (UAV), which finds its application for both military and civil purposes, has been considered where the composite shall be used. The utmost goal, therefore, is that the composite should have minimum weight and high strength when it is used for a UAV.

The polymer composite laminate of epoxy resin systems and graphene oxide reinforced with glass fiber has been fabricated by hand layup method. The fabricated laminate is further cut in to test specimens as per ASTM standards and tested for its strength and stiffness. As per the experimental studies the strength to weight ratio is increased compared to literature, this base material with combination of graphene we are using for an Aerospace applications such UAV, as a part of further research we are fabricating UAV with Graphene-Epoxy. The peak load carrying capacity is satisfactory for EPWM12 (epoxy woven mat 12 layers). The 3 Pt flexural strength and peak load carrying capacity is better than that for EPWM12 (epoxy woven mat 12 layers).

Epoxy with woven mat combination is good compared to the chopped mat where the filler material plays an important role to increase the strength of the polymer composites. As per the literature 1.5% of graphene oxide (GO) is added to all laminates which act as a filler material and increase the tensile strength.

Key Words: - Epoxy, Graphene, Unmanned Aerial vehicle, Composite, Laminate.

1. INTRODUCTION

1.1 Overview

Many of the modern technological developments that have taken place in the last few decades are due to the development of new materials and new processing techniques. Among the new materials that have come to stay, composite materials occupy an important place in every important field such as aerospace, defense, automobiles, civil infrastructure, biomaterials as well as sports and leisure. These materials originally developed for the use in aerospace applications have now become a part of daily life. The scope of application of composites being unlimited, these materials will dominate the materials field for a long period in the years to come. The aerospace industry needs high strength to weight ratio materials with stringent fatigue tolerance, impact resistance, reparability and now recyclability. Composite materials have emerged as the materials of choice for increasing the performance and reducing the weight and cost of military aircraft, general aviation aircraft, transport aircraft and space launch vehicles. In the Fig.1 **(Application of Composites on Flight Vehicles)** the major advancements have been made in the ability to design, fabricate, and analyze large complex aerospace structures.

Fig. 1 Applications of Composites on Aero Vehicles

1.2 Designing UAVs Using Composite Materials

The use of composites is reflected in the UAV industry. In 2009, a survey of 200 models by composite world found that all of the models have composites components and a number of cases reported the use of carbon fibre for the construction of airframes. However, the increased demand for payload capacity and drone performance made the industry switch to another composite for the construction of the drone structure: carbon fibre-reinforced polymers (CFRP) which are now the primary material used in the construction of the UAV airframes.

For example, a structure made of steel will weigh approximately 5 times more than a structure of the same strength made from CFRP. However, their high cost (5 to 25 times more expensive than glass fibre) has inhibited the use of this material in the industry. In addition, the material is electrically conductive which makes it unsuitable for certain applications.

1.3 Graphene Composites

Graphene oxide (GO) composites are carbon-based materials with excellent performance and low cost. They possess high Young’s modulus and tensile strength [1–3]. They are applied in a variety of civil, mechanical and aerospace applications. They also have highly advantageous mechanical properties and at the same time they are light and easy to manufacture [1]. GO materials are used in polymer composite systems as fillers to improve the mechanical properties of the parent polymer materials Epoxy – GO systems have the ability to produce light and strong materials with many useful features.

2. LITERATURE SURVEY

From the literature survey done so far and the search made to find out if there is a significant efforts made to utilise the composites for UAV fabrication it was observed that the information obtained is sparse and hence it encourage taking up a topic that is adopted in this research. In this research it is attempted to fabricate a UAV from the material development stage. As per the literature 1.5% GO to the epoxy matrix ratio increased the tensile strength, hardness and Young's modulus of the composite compared to the pure epoxy matrix. The same percentage of GO has constantly been used with a varying glass fibre (Chopped Mat & Woven Mat with different layers).

2.1 Future Scenario[14]

The potential of UAVs is very vast. In the 21st century, DRDO is committed to deliver state of-the-art UAV systems to the Indian Armed Forces. The technologies described above are the base for the future UAV development programmes. Futuristic programmes of DRDO include UCAV, micro and mini, multi-role, and solar powered UAVs. Technology predictions for the next decade envisage 50 per cent increase in endurance, silent engines, self-repairing, and damage compensating structures with real-time monitoring of structural health, rotorcraft of high speeds, multichannel data acquisition systems, full automatic control of flight and mission etc.

3. Materials and Methods

In this research the following reinforcements are used. Table 1 has the details of the names of the materials used in this research work.

Table 1: Names of the materials used in this research work

Sl.No	Materials
1	Epoxy (Resin) shown in Fig. 2
2	Glass Fibre (Woven Mat, Chopped Mat) shown in Fig. 3 & Fig.4 respectively
3	Graphene Oxide shown in Fig. 5

Fig. 2 Epoxy resin

Fig. 3 Woven Mat

Fig. 4 Chopped Mat

Fig. 5 Graphene Oxide

3.1 Fabrication of mould

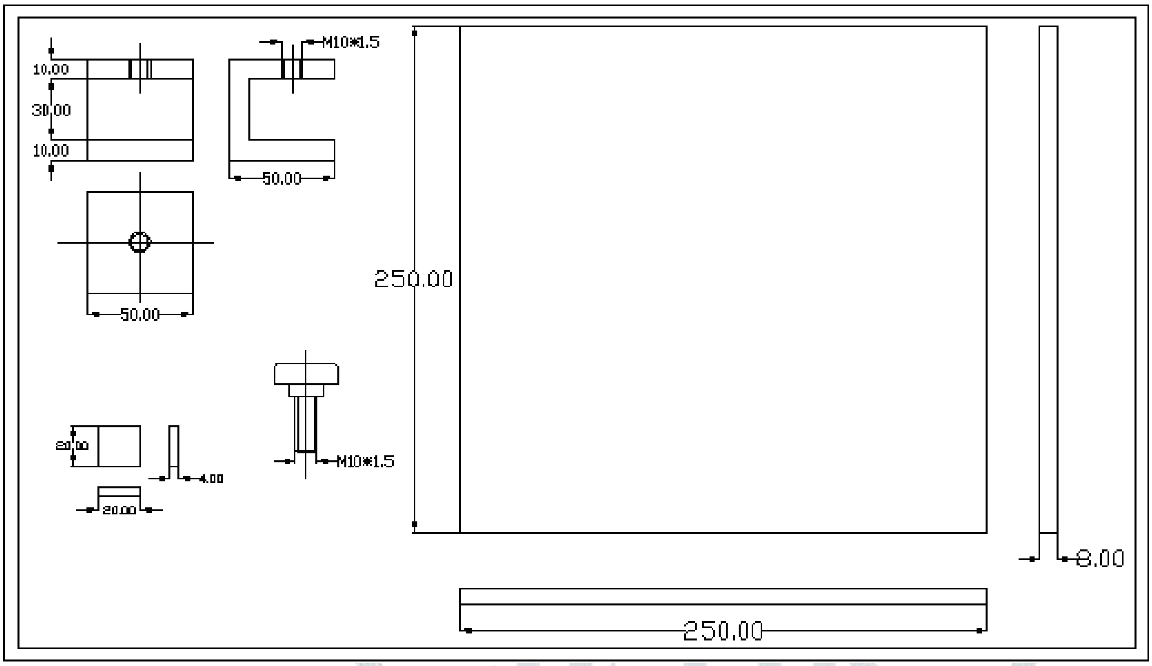


Fig. 6 Drawing for the fabrication mould

Fig. 7 Mould Assembly **Fig. 8 C-Clamp**

Materials which are used for producing PMC (polymer matrix composite) laminates with reinforcement are discussed in this part. Fig. 7 shows mould assembly used in this project. Two plates are having the dimensions of 250 mm x 250 mm and 10 mm thickness. These dimensions are selected according to the requirements of the fabrication process.

The spacers in between mould plates are used to maintain the Laminate thickness. Fig. 8 shows a C-Clamp, The C-Clamps are used in the mould preparation to apply load by using the screw threads.

3.2 Method of Preparation of Laminates

3.2.1 Hand Layup method

This method is the simplest method of composite processing where the infrastructure requirement for this method is minimal and processing steps are simple. In this research, to estimate the strength of a composite, laminates of epoxy resin are prepared by using hand lay-up method. The resin, hardener and Graphene are mixed in a beaker and the layers of fiber are cut in to the required number of pieces. Some wax will be applied to mould because the laminate should be barred from sticking to mould. To calculate the volume fraction of laminate the reinforcement is weighed and a laminate shall be prepared layer by layer.

In Table 2, the details of laminate specifications are given.

Table 2: Laminate Specifications

Sl.No	Laminate Code	Volume Fraction of Reinforcement	Volume Fraction of Resin (Matrix)
1	EPWM12	68%	32%
2	EPCM12	65.4%	34.6%
3	EPWM6	66.9%	33.1%
4	EPCM6	64.2%	35.8%

Below are given pictures of the laminates prepared in the laboratory for the purpose of this research.

Fig. 9 EPCM 6 Layers

Fig. 10 EPCM 12 Layers

Fig. 11 EP WM 6 Layers

Fig. 12 EPWM 12 Layers

The laminates are prepared for 12 Layers (Fig, 10& 12) and 6 Layers (Fig. 9 & 11) of fiber reinforcement with resin and Graphene oxide material that increases the strength of the composite.

4. Results and Discussions

Experiments were conducted to ascertain the strength of different composite laminates used in the research. A mini universal testing machine (UTM) was used. Both the tensile and compressive strengths were determined and presented below.

After the tests were carried out for all laminates and results plots and analyzed, a typical laminate was chosen to numerically verify if the same load produces the required deformation and gives the information that is required to justify the validity of the results obtained from experiment and simulation.

Below is provided the results of experiments.

4.1 TENSILE TEST

The explanation for a laminate code is given below:

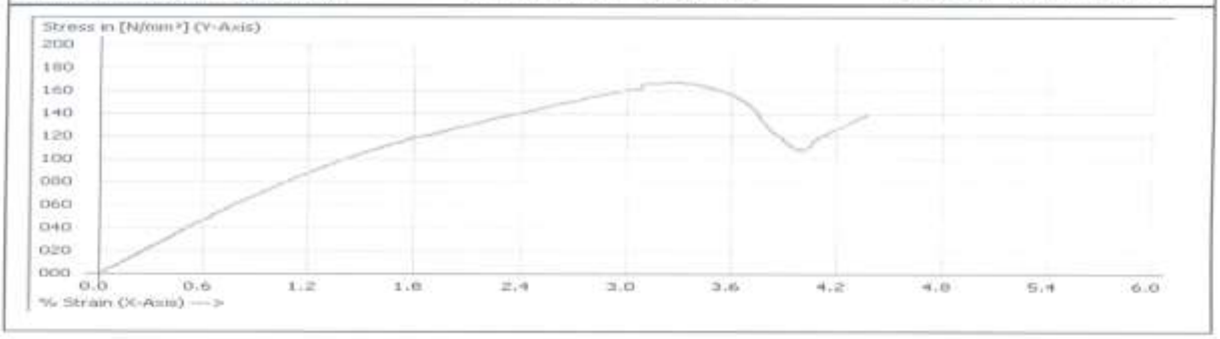
For example, EPCM6:- Epoxy (Resin), Chopped mat, 6 layers. GO- Graphene Oxide (Filler), WM (Woven mat).

The tensile tests were conducted for EPWM12 and the stress-strain plot(Fig 15) were obtained. Cross-section of the material is 32 mm^2. The maximum load is 5331 N. The % elongation is 4.39. The ultimate tensile stress is 166.60 N/mm^2. The test is carried out for Epoxy – Woven mat – 12 Layers with 1.5% GO filler material.

Epoxy Woven Mat 12 Layers

Multigraph Report

Test Name : TENSILE TEST	Test Type : Normal	Test Mode : Tensile
Elongation Device : CrossHead	Test Parameter : Peak Load	Test Speed [mm/min]: 2.00



Sample Details :

Sample No.	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
000001	32.00	5,331.00	4.39	0.63	166.60	3797.81

Summary Report :

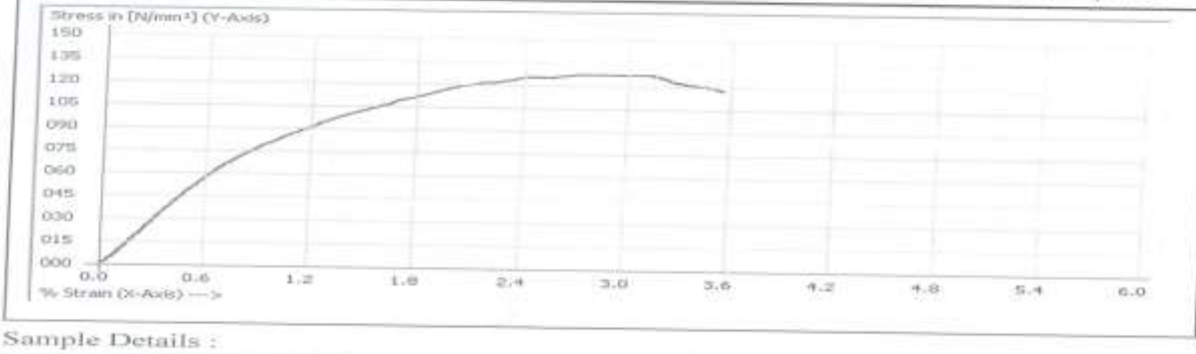
	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
Min	32.00	5331.00	4.39	0.63	166.60	3797.81
Max	32.00	5331.00	4.39	0.63	166.60	3797.81
Avg	32.00	5331.00	4.39	0.63	166.60	3797.81
Std Dev.	0.00	0.00	0.00	0.00	0.00	0.00
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Median	32.00	5331.00	4.39	0.63	166.60	3797.81

Fig. 13 Stress-Strain plot for EPWM12 Layers laminate

Epoxy Chopped Mat 12 Layers

Multigraph Report

Test Name : TENSILE TEST
Elongation Device : CrossHead
Test Type : Normal
Test Parameter : Peak Load
Test Mode : Tensile
Test Speed [mm/min]: 2.00



Sample Details :

Sample No.	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
000002	40.00	5,085.00	3.57	0.63	127.11	3563.91

Summary Report :

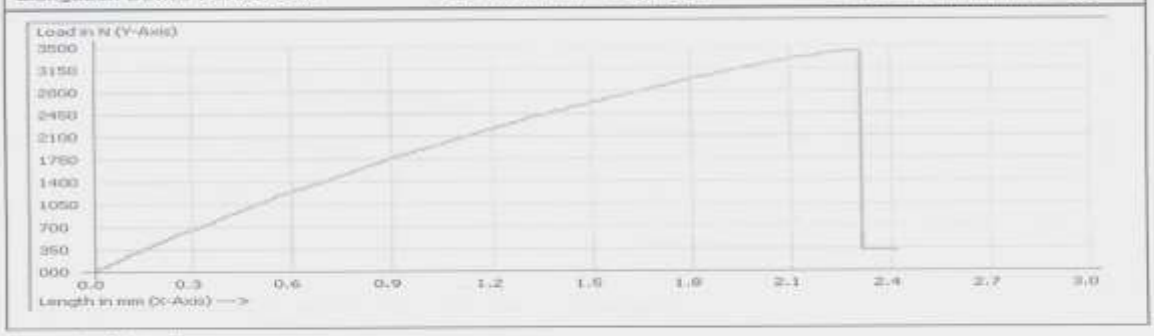
	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
Min	40.00	5085.00	3.57	0.63	127.11	3563.91
Max	40.00	5085.00	3.57	0.63	127.11	3563.91
Avg	40.00	5085.00	3.57	0.63	127.11	3563.91
Std Dev.	0.00	0.00	0.00	0.00	0.00	0.00
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Median	40.00	5085.00	3.57	0.63	127.11	3563.91

Fig. 14 EPCM12 Layers laminate

Epoxy Woven Mat 6 Layers

Multigraph Report

Test Name : TENSILE TEST
Elongation Device : CrossHead
Test Type : Normal
Test Parameter : Peak Load
Test Mode : Tensile
Test Speed [mm/min]: 2.00



Sample Details :

Sample No.	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
000001	28.80	3,411.00	3.03	12.28	118.45	3915.45

Summary Report :

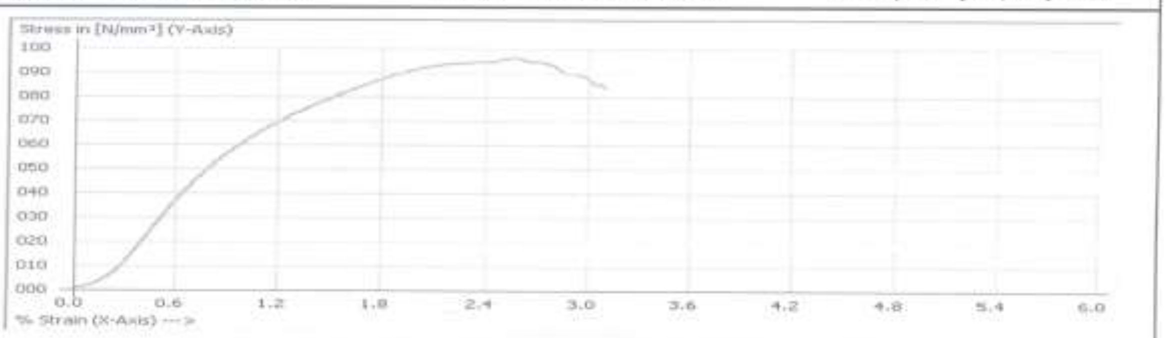
	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
Min	28.80	3411.00	3.03	12.28	118.45	3915.45
Max	28.80	3411.00	3.03	12.28	118.45	3915.45
Avg	28.80	3411.00	3.03	12.28	118.45	3915.45
Std Dev.	0.00	0.00	0.00	0.00	0.00	0.00
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Median	28.80	3411.00	3.03	12.28	118.45	3915.45

Fig.15 EPWM6 Layers laminate

Epoxy Chopped Mat 6 Layers

Multigraph Report

Test Name : TENSILE TEST | Test Type : Normal | Test Mode : Tensile
Elongation Device : CrossHead | Test Parameter : Peak Load | Test Speed [mm/min]: 2.00



Sample Details :

Sample No.	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
000001	72.00	6,916.00	3.12	0.47	96.06	3083.19

Summary Report :

	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
Min	72.00	6916.00	3.12	0.47	96.06	3083.19
Max	72.00	6916.00	3.12	0.47	96.06	3083.19
Avg	72.00	6916.00	3.12	0.47	96.06	3083.19
Std Dev.	0.00	0.00	0.00	0.00	0.00	0.00
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Median	72.00	6916.00	3.12	0.47	96.06	3083.19

Fig. 18 EPCM6 Layers laminate

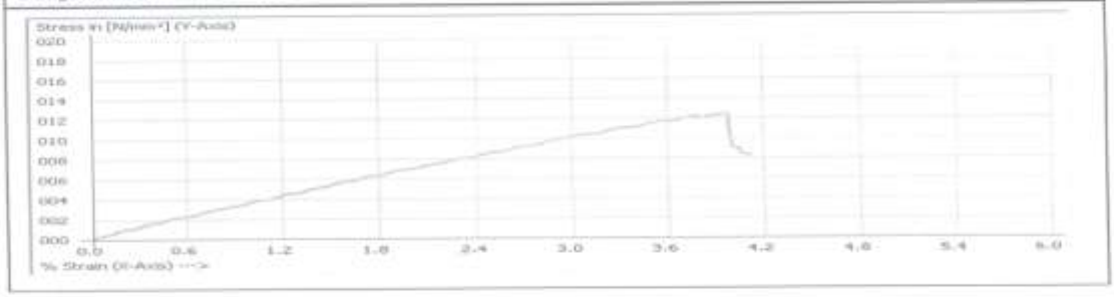
COMPRESSION MODE 3 PT BEND FEXTURAL TEST

The flexural tests were conducted for the same laminates EPWM12(Fig.19), EPCM12 (Fig. 20), EPWM6 (Fig.21), EPCM6 (Fig.22).

Epoxy Woven Mat 12 Layers

Multigraph Report

Test Name : 3PT BEND FLEXURAL TEST | Test Type : Normal | Test Mode : Compression
Elongation Device : CrossHead | Test Parameter : Peak Load | Test Speed [mm/min]: 1.00



Sample Details :

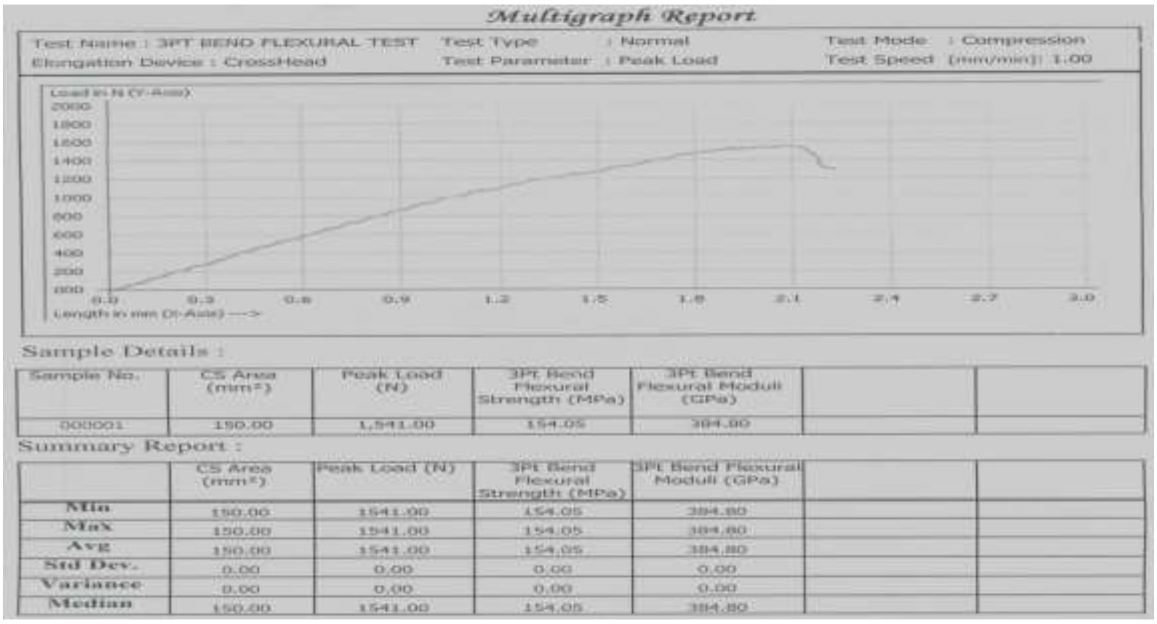
Sample No.	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
000001	112.50	1,394.00	247.90	-3,332.91		

Summary Report :

	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
Min	112.50	1394.00	247.90	3332.91		
Max	112.50	1394.00	247.90	3332.91		
Avg	112.50	1394.00	247.90	3332.91		
Std Dev.	0.00	0.00	0.00	0.00		
Variance	0.00	0.00	0.00	0.00		
Median	112.50	1394.00	247.90	3332.91		

Fig.19 Stress-strain curve for EPWM12 under 3 PT bend flexural test

Epoxy Chopped Mat 12 Layers


Multigraph Report

Test Name : 3PT BEND FLEXURAL TEST Test Type : Normal Test Mode : Compression
Elongation Device : CrossHead Test Parameter : Peak Load Test Speed (mm/min): 1.00

Sample Details :

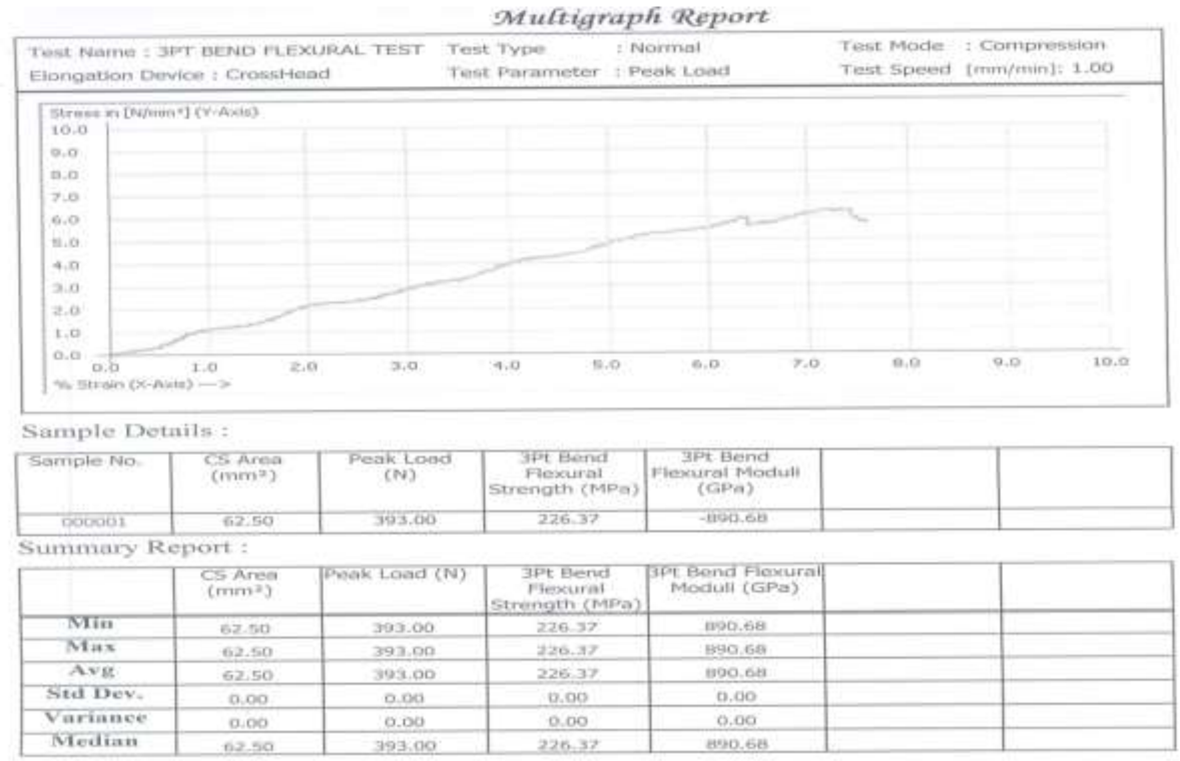
Sample No.	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
000001	150.00	1,541.00	154.05	384.80		

Summary Report :

	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
Min	150.00	1541.00	154.05	384.80		
Max	150.00	1541.00	154.05	384.80		
Avg	150.00	1541.00	154.05	384.80		
Std Dev.	0.00	0.00	0.00	0.00		
Variance	0.00	0.00	0.00	0.00		
Median	150.00	1541.00	154.05	384.80		

Fig.20 Stress-strain curve for EPCM12 under 3 PT bend flexural test

Epoxy Woven Mat 6 Layers


Multigraph Report

Test Name : 3PT BEND FLEXURAL TEST Test Type : Normal Test Mode : Compression
Elongation Device : CrossHead Test Parameter : Peak Load Test Speed (mm/min): 1.00

Sample Details :

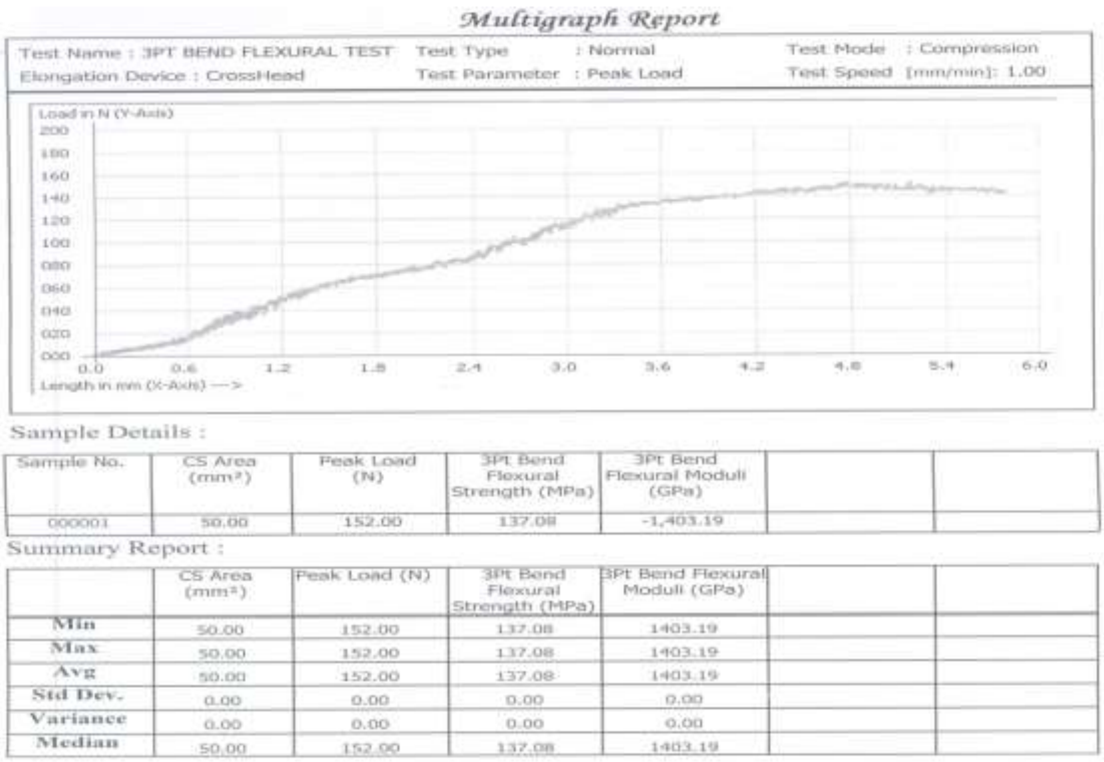
Sample No.	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
000001	62.50	393.00	226.37	-890.68		

Summary Report :

	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
Min	62.50	393.00	226.37	890.68		
Max	62.50	393.00	226.37	890.68		
Avg	62.50	393.00	226.37	890.68		
Std Dev.	0.00	0.00	0.00	0.00		
Variance	0.00	0.00	0.00	0.00		
Median	62.50	393.00	226.37	890.68		

Fig.21 Stress-strain curve for EPWM6 under 3 PT bend flexural test

Epoxy Chopped Mat 6 Layers


Multigraph Report

Test Name : 3PT BEND FLEXURAL TEST Test Type : Normal Test Mode : Compression
Elongation Device : CrossHead Test Parameter : Peak Load Test Speed [mm/min]: 1.00

Sample Details :

Sample No.	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
000001	50.00	152.00	137.08	-1,403.19		

Summary Report :

	CS Area (mm²)	Peak Load (N)	3Pt Bend Flexural Strength (MPa)	3Pt Bend Flexural Moduli (GPa)		
Min	50.00	152.00	137.08	1403.19		
Max	50.00	152.00	137.08	1403.19		
Avg	50.00	152.00	137.08	1403.19		
Std Dev.	0.00	0.00	0.00	0.00		
Variance	0.00	0.00	0.00	0.00		
Median	50.00	152.00	137.08	1403.19		

Fig.22 Stress-strain curve for EPCM6 under 3 PT bend flexural test

COMPARISON OF RESULTS

Table 3 : Tensile Test Results for 4 laminates

Laminate Code	EPWM12	EPCM12	EPWM6	EPCM6
Peak Load (N)	**5331 N**	5085 N	3411 N	6916 N
Ultimate Tensile Strength (N/mm^2)	**166.6 N/mm^2**	127.11 N/mm^2	118.45 N/mm^2	96.06 N/mm^2
Young's Modulus (N/mm^2)	**3797.81 N/mm^2**	3563.91 N/mm^2	3915.45 N/mm^2	3083.19 N/mm^2
% of Elongation	**4.39**	3.57	3.03	3.12

Table 4: Compression Test Results for 4 laminates

Laminate Code	EPWM12	EPCM12	EPWM6	EPCM6
Peak Load (N)	**1394.00**	1541.00	393.00	152.00
3 Pt Flexural Strength (MPa)	**247.90**	154.05	226.37	137.08

From the Table 3 it is observed that the ultimate tensile strength of EPWM12 is better than any one of the remaining 3 laminates and though the value of peak load used for EPCM6 is higher than other three , the peak load carrying capacity is satisfactory for EPWM12 (Epoxy woven mat 12 layers).

From the Table 4 it is observed that the 3 PT flexural strength and peak load carrying capacity is better than that for EPWM12 (epoxy woven mat 12 layers).

So epoxy with woven mat combination is better compared to the chopped mat where the filler material plays an important role to increase the strength of the polymer composites.

5. CONCLUSION

In this research an experimental investigation has been carried out to develop new Polymer Matrix Composite using commercially available epoxy resin systems with graphene and Glass fiber reinforcement. Graphene is reinforced due to its better properties in a material field. Laminates are prepared by hand layup method, the prepared laminates are cut in to standard specimens as per ASTM standards and Test for their Tensile, compressive strengths to determine the best materials for aerospace application, as per experimental results it is observed that the ultimate tensile strength of EPWM12 is better than any one of the remaining 3 laminates and though the value of peak load used for EPCM6 is higher than other three, the peak load carrying capacity is satisfactory for EPWM12 (epoxy woven mat 12 layers). The 3 PT flexural strength and peak load carrying capacity is better than that for EPWM12. Due to Graphene Reinforcement the epoxy composite will have high Strength to weight ratio and stiffness in woven mat fiber.

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