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Experimental and Numerical Validation of Unmanned Aerial Vehicle Structure Fabricated using Graphene based Polymer Matrix Composites

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ABSTRACT:

This paper describes the investigation of the polymer matrix composite laminate of epoxy resin systems and graphene oxide (GO) reinforced with glass fiber. The laminates of epoxy glass fiber reinforced with GO has been fabricated by hand layup method and the fabricated laminate is further cut into test specimens as per ASTM standards and tested for their strength and stiffness. As per the experimental studies, the strength to weight ratio is increased. An attempt has also been made to observe how the different volume addition (1.5%, 3%, 4.5% and 6%) of GO to epoxy matrix has affected the tensile strength, Young's modulus and % elongation of the laminate made of composite. The outcome of the experimental characterization of the composites has encouraged further choosing epoxy / GO (1.5% by volume) towards fabricating a simplified version of UAV. Laminate code EPWM12, an epoxy / GO woven mat 12-layer composite, has the satisfying peak load carrying capacity as well as three-point flexural strength as opposed to other four materials considered in this study. The Monte Carlo simulation showed that likelihood of EPWM12 material being safe for UAV is 96%.

KEYWORDS:

Epoxy; Graphene; Unmanned aerial vehicle; Composite laminate; Tensile strength

CITATION:

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1. Introduction

The use of composites is reflected in the Unmanned Aerial Vehicle (UAV) industry. In 2009, a survey of 200 models by Composite World found that all of the models have composite components and a number of cases reported the use of carbon fibre for the construction of 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. Graphene oxide (GO) composites are carbon-based materials with excellent performance and low cost. They possess high Young's modulus (E), % elongation (ε) and ultimate tensile strength (UTS) [1-3]. They have highly advantageous mechanical properties, light weight and easy to manufacture [1]. Tanwer [6] studied the inter-laminar fracture toughness of fly ash/glass fiber reinforced epoxy composites versus glass fibre-epoxy composites. It was noted that tensile strength is lower and moisture uptake is higher for the former.

Investigation on mechanical properties of epoxy-based hybrid composites reinforced with Sisal / SIC / glass fibre [7-8] prompted an overall urge to apply the composites in various relevant fields. There has been an attempt to fabricate a UAV using epoxy /GO. An attempt has also been made to observe how the different volume addition (1.5%, 3%, 4.5% and 6%) of GO to epoxy matrix has affected the tensile strength, Young's modulus and % elongation of the laminate made of composite. A comparison of strength has also been mentioned when GO, a wonderful filler material when compared to others [3-4], is added to epoxy and GO is not added to it. The outcome of the experimental characterization of the composites has encouraged further choosing GO/ Epoxy (1.5 % in volume) towards fabricating a simplified version of UAV structure and assess its structural integrity.

From the review of relevant literature [1], it was noted that an addition of 1.5% volume of GO to the epoxy matrix ratio has increased the tensile strength, hardness and Young's modulus of the composite compared to the pure epoxy matrix (without GO). In the present study this was verified for the composites laminates considered for the fabrication of an UAV. First of all, the details of materials and methods of manufacturing of laminates have been considered and then their characterisation [5] was done before being recommended for the fabrication of the UAV structures [9-10]. The authors have attempted to demonstrate the suitability of a polymer matrix composite, EPWM12 prepared using hand layup method, for UAV. The simplified UAV then has been tested in the field to confirm that the material recommended from this study is the right choice.

2. Materials and methods

In this research, epoxy (resin), glass fibre (woven mat, chopped mat) and GO are used. The mechanical properties, volume fraction of matrix and reinforcement are detailed in Table 1. Two laminated plates having the dimensions of 250 mm × 250 mm and 10 mm thickness are manufactured using wet layup method. These dimensions are selected according to the requirements of the fabrication process. The spacers in between the mould plates are used to maintain the laminate thickness. Fig. 1 shows the drawing of the fabrication mould. The mould assembly for the composite plate manufacturing is shown in Fig. 2. Fig. 3 shows a C-clamp, which is used in the mould preparation to apply load by using the screw threads. This method is the simplest method of composite processing where the infrastructure requirement for this method is minimal and processing steps are simple [11].

Table 1: % by volume of reinforcement and mechanical properties

Epoxy /GO composite	Epoxy vol. %	EP + 1.5 vol. %	EP + 3.0 vol. %	EP + 4.5 vol. %	EP + 6 vol. %
GO content	0	1.5	3.0	4.5	6.0
Epoxy resin	70	68	65.4	66.9	64.2
Hardener	30	32	35	33	36
UTS (MPa)	97	141.62	118.34	108.64	103.79
E (MPa)	2459.1	3563.91	3781.31	4046.0	4317.08
ε (%)	3.07	4.39	4.35	4.49	4.94

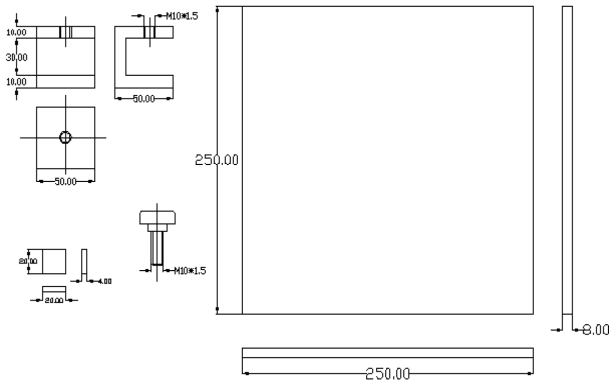


Fig. 1: Drawing for the fabrication mould

Fig. 2: Mould assembly

Fig. 3: C-clamp

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 GO are mixed in a beaker and the layers of fiber are cut into the required number of pieces. Some wax is 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 is prepared layer by layer. Figs. 4 to 7 show the fabricated laminates for characterisation tests. The letter W & C in the code refers woven and chopped glass fiber mat respectively. The last digit of the laminate code 6 or 12 infers the number of reinforcement layers. The GO content is varied as per the resin constituents in Table 1.

Fig. 4: EPCM 6 layers

Fig. 5: EPCM 12 layers

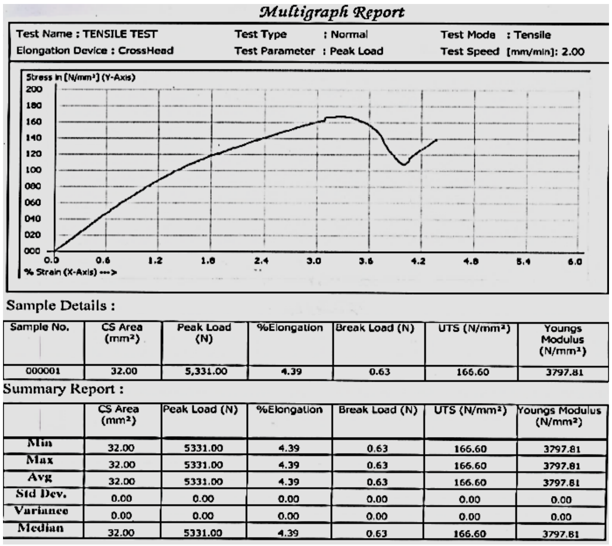
Fig. 6: EPWM 6 layers

Fig. 7: EPWM 12 layers

3. 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. Tensile tests were carried out for all laminates and results are 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. The stress-strain plot for EPWM12 (1.5% GO filler material) laminate is shown in Fig. 8. The cross-section of the tensile test coupon is 32 mm^2. The maximum load is 5331 N. The % elongation is 4.39. From these inputs, the calculated UTS is 166.6 MPa. Table 2 summarises the results of tensile and flexure tests. GO addition of 1.5% in epoxy has enhanced its UTS by over 65% from pure epoxy. Epoxy/GO (1.5%) material's UTS is 50% higher than jute. Young's modulus of epoxy + GO (1.5%) composite is 66% higher than that of pure epoxy and almost 4 times that of jute. The box plot shown in Fig. 9 depicts the median and quartile of the % elongation of each material that is considered and compared during the study to understand that epoxy/GO is superior. Epoxy/GO has a higher median (3.3%) and maximum value of elongation

(4.3%) compared to that of pure epoxy and jute. These benefits in UTS and Young's have encouraged the authors to prepare the laminates with GO additives for the UAV structures.


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. 15: Tensile stress-strain plot for EPWM12 + 1.5% GO laminate

Table 2: Tensile test results summary

Laminate code	%Vol. matrix	Load (N)	UTS (MPa)	E (MPa)	ε (%).
EPWM12 (1.5% GO)	32	5331	166.60	3798	4.39
EPCM12 (3% GO)	35	5085	127.11	3564	3.47
EPWM6 (4.5% GO)	33	6916	96.06	3083	3.12
EPCM6 (6% GO)	36	3411	118.45	3915	3.03
CMJUTE 6	29	NA	108.33	968	2.00
WMJUTE 6	26	NA	75.47	968	4.00

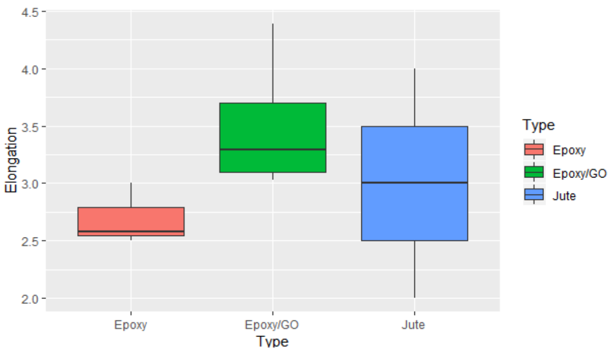
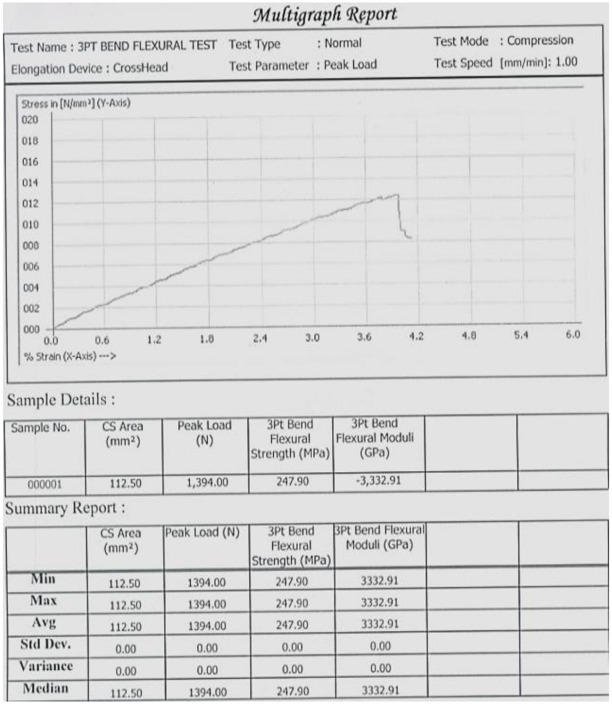


Fig. 9: % Elongation results from tensile test

The flexural tests were conducted for all the laminates - EPWM12, EPCM12, EPWM6 and EPCM6. The stress-strain plot for EPWM12 (1.5% GO) is presented in Fig. 10. It shows a linear relationship between the flexural stress and deformation. Fig. 11 shows a comparison of flexural stress (ordinate as non-dimensional by dividing their individual maximum) vs. Deformation (abscissa in %). It is noted that EPWM12 with 1.5% GO filler material (inferred as GO1half in the plot) can actually bear a higher deformation compared to the other 3 composites. So, EPWM12 with 1.5% GO laminate was again tested and characterized through experiment and numerical computation for its strength and compared with pure epoxy (inferred as NoGO in the plot) and 3% GO (inferred as GO3 in the plot) in Fig. 12. The numerical assessment of flexural stress vs. Deformation matches fairly well with that of its experimental values.


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. 10: Flexural stress-strain plot for EPWM12 + 1.5% GO laminate

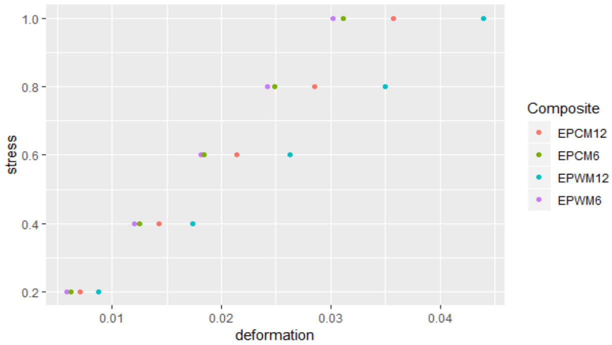


Fig. 11: Comparison of stress-deformation for four composites under three-point bend flexural test

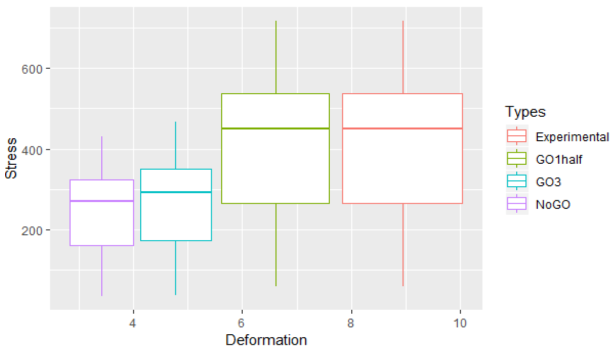


Fig. 12: Box plots for flexural stress and maximum deformation obtained from numerical study and experimental testing

A simplified UAV (mass of 1200 g, wing span of 700 mm, fuselage length of 600mm and cross section of 120mm × 120mm) was fabricated using the EPWM12 with 1.5% GO filler material polymer matrix composite using the hand layup method. Then the wing and fuselage of UAV were tested for its strength and resistance using three-point bending test. Figs. 13 and 14 show the bending test arrangement for the wing and fuselage respectively. The tests were conducted in the beam test set-up (the maximum load it can exert is 50 kgf, the space between the two support mounts is 800 mm. The overall variation of stress and deformation are presented in Fig. 15. The failure happens at 700 MPa and the matching between the experimental results and numerical values is quite good.

Fig. 13: Wing bending test

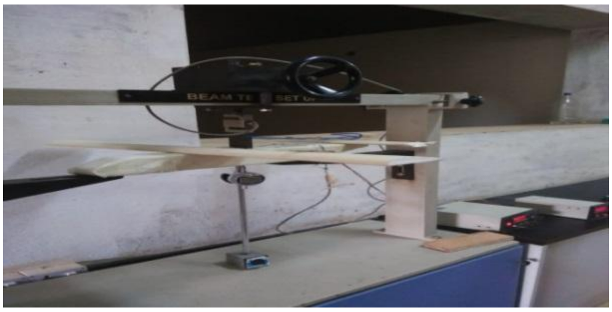


Fig. 14: Fuselage bending test

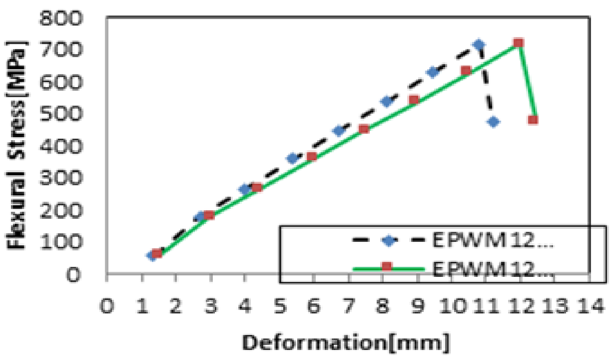


Fig. 15: Flexural stress vs. Deformation from bending test for wing (continuous line) and fuselage (dotted line)

Monte Carlo simulation has been used to model the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables. It is a technique used to understand the impact of risk and uncertainty in prediction and forecasting models. In this research we used six models of laminates for choosing the best material for UAV development. Among the six laminates tested, EPWM12 with 1.5% GO filler material is qualified to be the best material that was taken for fabrication of UAV. Fig. 16 shows the outcome of Monte Carlo simulation. The simulation was run for 500 times to see the behavior of the stress and strain in EPWM12+1.5%GO model for uncertain and random input values of stress and strain to meet Tsai-Wu failure criterion(<=1.0). The likelihood of the EPWM12 being safe for UAV is 96%.

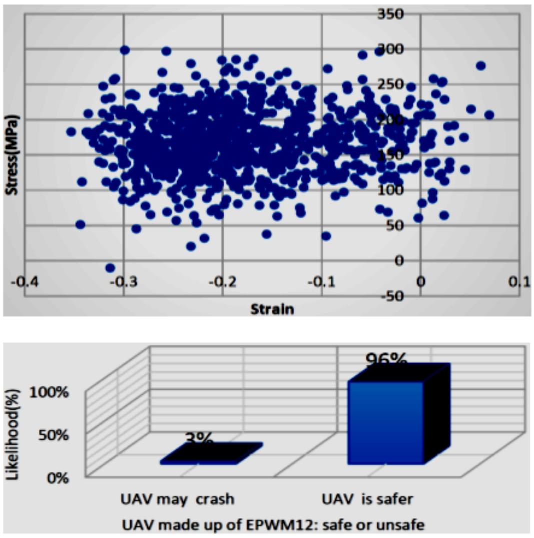


Fig. 16: Monte Carlo simulation of EPWM12

4. Conclusion

In this experimental study, an attempt has been made to develop polymer matrix composite laminates using commercially available epoxy resin systems with GO and glass fiber reinforcement and characterize the same before recommending it for aerospace application. Laminates are prepared by hand layup method. The prepared laminates are cut into standard specimens as per ASTM standards and tested for their tensile and flexural strengths to determine the best materials for aerospace application. As per the experimental results, it is observed that the ultimate tensile strength of EPWM12 with 1.5% GO filler material is better than any one of the remaining three 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.

The three-point flexural strength and peak load carrying capacity is better for EPWM12. Due to GO reinforcement, the epoxy composite will have high strength to weight ratio and stiffness in woven mat fiber. Epoxy /GO has a higher median (3.3%) and maximum value of elongation (4.3%) compared to that of the pure epoxy (no graphene is added) and jute. The Young's modulus of epoxy /GO composite is 66% higher than that of pure epoxy and almost 4 times that of jute. The higher %vol. of GO addition to epoxy resin has little or no impact on the strength and Young's modulus. For the same bending load, the fuselage has deformed more than the wing by around 60% during the bending test. One of the reasons could be the cross-section of fuselage and fiber orientation. The Monte Carlo simulation showed that the likelihood of EPWM12 material being safe for UAV wing and fuselage is 96%.

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