Development of Unmanned Aerial Vehicle by Graphene Based Polymer Matrix Composites

Vijaya Kumar R, S K Maharana

Abstract: 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 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. A comparison of strength has also been mentioned when GO, a wonderful filler material, is added to epoxy and GO is not added to it. The outcome of the experimental characterization of the composites has encouraged further to choose Epoxy/GO (1.5% in 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%.

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

I. INTRODUCTION

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. 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 and tensile strength [1–3]. They also have highly advantageous mechanical properties and at the same time they are light and easy to manufacture [1].

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An investigation was carried out by some of the previous researchers [7] on inter-laminar fracture toughness of fly ash/glass fiber reinforced epoxy composites versus glass fibre-epoxy composites. In the outcome 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[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, is added to epoxy and GO is not added to it. The outcome of the experimental characterization of the composites has encouraged further to choose GO/Epoxy (1.5 % in 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.

From the review of the relevant literature 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 graphene oxide). In the present study this was verified for the composites laminates considered for the fabrication of aerospace application – a UAV. First of all the details of materials and methods of manufacturing of laminates have been considered and then their characterisation was done before being recommended for the fabrication of UAV. 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.

II. 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. 1
2	Glass Fibre (Woven Mat, Chopped Mat) shown in Fig. 2 & Fig.3 respectively
3	Graphene Oxide shown in Fig. 4

The volume fraction of matrix and reinforcement are detailed in Table 2.

Table 2: Volume % of Reinforcement and UTS, YM, % elongation

Epoxy/GO composite	Content of GO	Epoxy Resin (vol.%)	Hardener (vol.%)	Ultimate Tensile Strength(N/mm^2)	Young's modulus(N/mm^2)	%Elongation
Pure Epoxy	0	70	30	97	2459.10	3.07
EP+1.5 vol.%	1.5	68	32	141.62	3563.91	4.39
EP+3.0 vol.%	3	65.4	35	118.34	3781.31	4.35
EP+4.5 vol.%	4.5	66.9	33	108.64	4046.00	4.49
EP+6 vol.%	6	64.2	36	103.79	4317.08	4.94

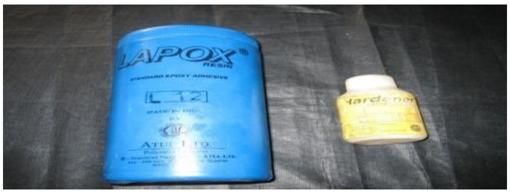

Fig. 1 Epoxy resin

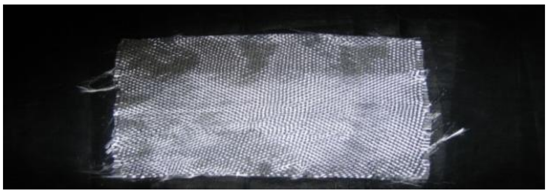

Fig. 2 Woven Mat

Fig. 3 Chopped Mat

Fig. 4 Graphene Oxide

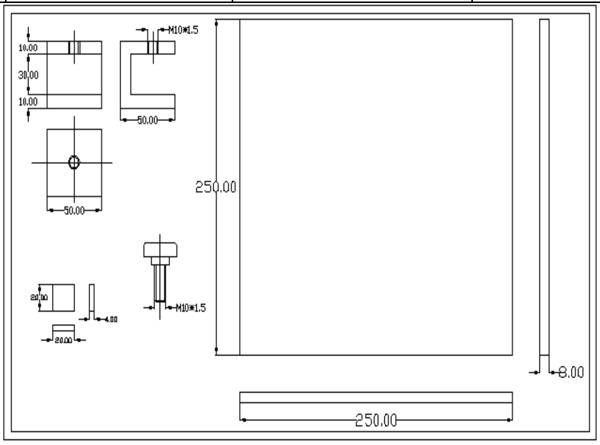

Fig. 5 Drawing for the fabrication mould

Fig. 6 Mould Assembly

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Fig. 7 C-Clamp

Materials which are used for producing PMC (polymer matrix composite) laminates with reinforcement are discussed in this part.

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.7 shows a C-Clamp, The C-Clamps are used in the mould preparation to apply load by using the screw threads.

2.1 Method of Preparation of Laminates

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 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.

In the Table 3, the details of laminate specifications are given. Along with the specifications are mentioned how properties change across different laminate codes.

Table 3: Laminate Specifications

LAMINATE CODE	EPWM12	EPCM12	EPWM6	EPCM6	CMJUTE 6	WMJUTE6	Behaviour
Volume Fraction of Reinforcement	0.68	0.65	0.67	0.64	0.71	0.74	
Volume Fraction of Resin (Matrix)	0.32	0.35	0.33	0.36	0.29	0.26	
Peakload(N)	5331	5085	6916	3411	NA	NA	
Ultimate Tensile Strength(N/mm^2)	166.60	127.11	96.06	118.45	108.33	75.47	
Young's Modulus(N/mm^2)	3798	3564	3083	3915	968	968	
% of Elongation	4.39	3.47	3.12	3.03	2.00	4.00	

The Fig.8 is depicting a comparison of Ultimate Tensile Stress of three different materials: Pure Epoxy, Epoxy/GO and Jute.The GO addition in Epoxy has enhanced its strength by over 65% from the pure Epoxy and Epoxy/GO material's strength is 50% higher than Jute. Fig.9 shows the comparison of Young's modulus of the same three materials. The Young's modulus of Epoxy +GOcomposite is 66% higher than that of pure Epoxy and almost 4 times that of Jute.

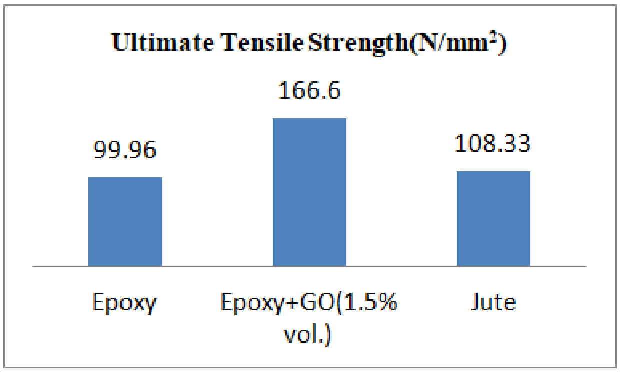

Fig.8 Comparison of Ultimate Tensile Strength for three materials: Pure Epoxy, Epoxy/GO and Jute

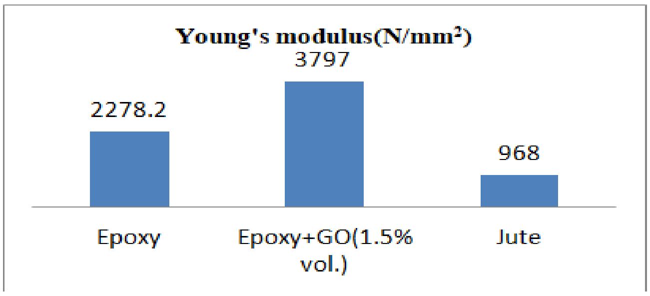

Fig.9 Comparison of Young's modulus for three materials: Pure Epoxy, Epoxy/GO and Jute

Fig.10 EPCM 6 Layers

The above mentioned justification for taking Epoxy/GO for the study has encouraged the authors to prepare the laminates as shown in the Fig. 10-13.

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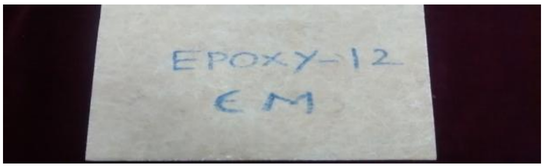


Fig. 11 EPCM 12 Layers

Fig. 12 EP WM 6 Layers

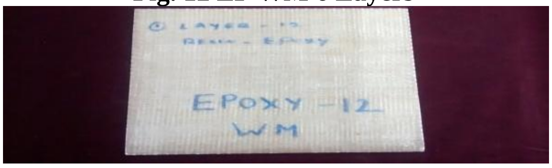


Fig. 13 EPWM 12 Layers

The laminates are prepared for 12 Layers (Fig.11& 13) and 6 Layers (Fig. 10 & 12) of fiber reinforcement with resin and Graphene Oxide material.

III. 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.

3.1 Tensile Test

Below is presented the outcome of experimental characterization of EPWM12. 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 has been carried out for Epoxy – Woven mat – 12 Layers with 1.5% GO filler material.

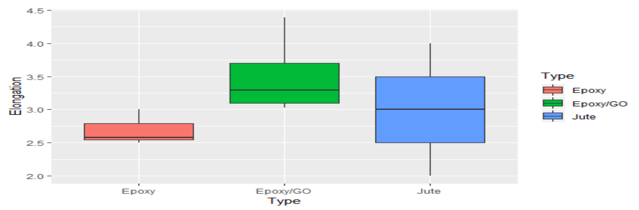
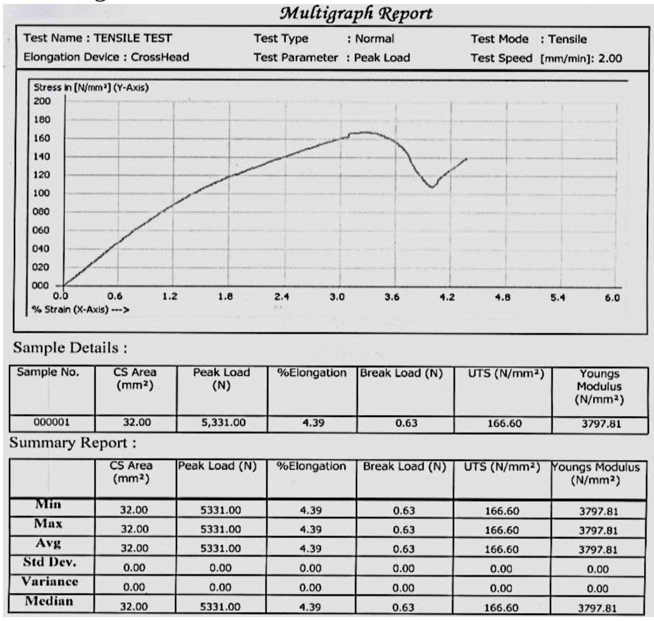


Fig. 14 Elongation of three key types of materials: Pure Epoxy, Epoxy/GO and Jute

The box plot shown in the Fig. 14 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 the pure Epoxy and Jute. The most typical laminate is EPMW12 for which characterization report is presented in Fig. 15. Similarly experiments were conducted for remaining 3 cases such as EPCM12, EPWM6 and EPCM6.



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 :

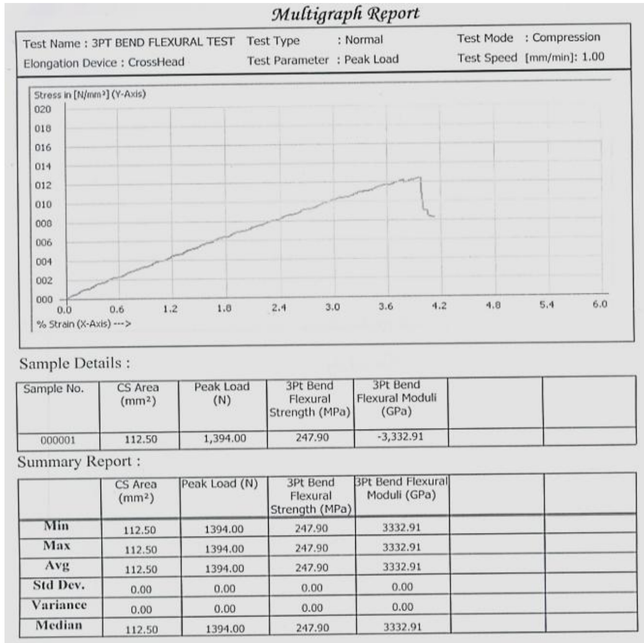
	CS Area (mm²)	Peak Load (N)	%Elongation	Break Load (N)	UTS (N/mm²)	Youngs Modulus (N/mm²)
Min	32.00	5331.00	4.39	0.63	166.60	3797.81
Max	32.00	5331.00	4.39	0.63	166.60	3797.81
Avg	32.00	5331.00	4.39	0.63	166.60	3797.81
Std Dev.	0.00	0.00	0.00	0.00	0.00	0.00
Variance	0.00	0.00	0.00	0.00	0.00	0.00
Median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

Fig. 15 Stress-Strain plot for EPWM12 Layers laminate

3.2 Three-Point Flexural Test

The flexural tests were conducted for the same laminates:EPWM12, EPCM12, EPWM6 and EPCM6. Below is shown the plot for EPWM12 in Fig.16. It shows the linear relationship between the flexural stress and deformation. Fig.17 shows a comparison of flexural stress (ordinate in MPa) versus deformation (abscissa in %).

Epoxy Woven Mat 12 Layers



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.16 Stress-strain curve for EPWM12 under three-point bend flexural test

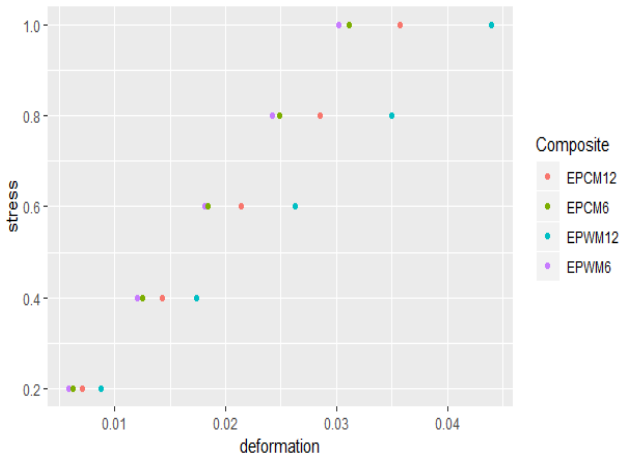


Fig.17 Comparison of stress-deformation for four composites under three-point bend flexural test

In the plot shown in Fig.17, the stress for each of the composites was made non-dimensional by dividing their individual maximum value

and then the deformation was noted. It is noted that EPWM12 can actually bear a higher deformation compared to the other 3 composites. So, EPWM12(already added with 1.5% vol. of GO, shown as GO1half in the plot) was again tested and characterized with two types of situations (experiment and numerical computation) for its strength with pure Epoxy and 3.0% vol. of GO(shown as GO3 in the plot). It was confirmed that the numerical assessment of flexural stress versus deformation matches fairly well with that of its experimental values. The pure Epoxy(no GO is added) is shown as NoGO in the plot.

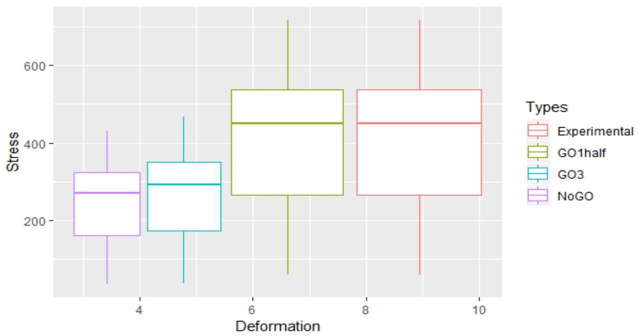


Fig.18 Boxplots for flexural stress and maximum deformation obtained from numerical study and experimental testing

3.3 Application of EPWM12 composites to UAV and its testing

Bending Test

A simplified UAV (mass of 1200 gm, wing span of 700 mm, fuselage length of 600 mm and cross section of 120 mm x 120 mm) was fabricated using the EPWM12 using the hand layup method and later it was tested for its strength and resistance using bending tests for wing and fuselage . The tests were conducted in the beam test set-up (the maximum load it can exert is 50 kg_f, the space between the two jaws/mount is 800 mm). Fig.19 and 20 show the bending test arrangement for wing as well as fuselage respectively. The overall variation of stress and deformation has been shown in Fig.21. The failure happens at 700 MPa and the matching between the experimental results and numerical values is quite good.

Fig.19 Wing bending test

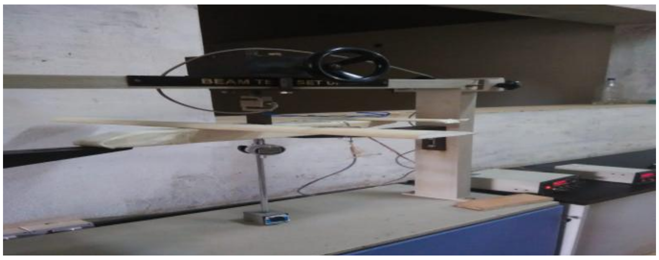


Fig.20 Fuselage bending test

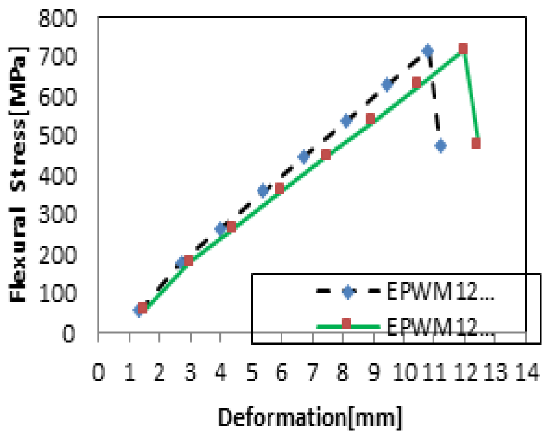


Fig.21 Flexural stress versus deformation variation during bending test for both wing and fuselage

3.4 The Advanced Monte Carlo Simulation

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 which is one of the applications considered. Among the six models EPWM12 qualified to be the best material that was taken for fabrication of UAV.

In the Fig. 22 is shown the outcome of Monte Carlo simulation. The simulation was run for 500 times to see the behavior of the stress and strain EPWM12 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%. This was decided based upon the Tsai-Wu failure criterion. The same material failed to qualify the criterion as well. The likelihood of failure of UAV, if EPWM12 is chosen, is only 3%.

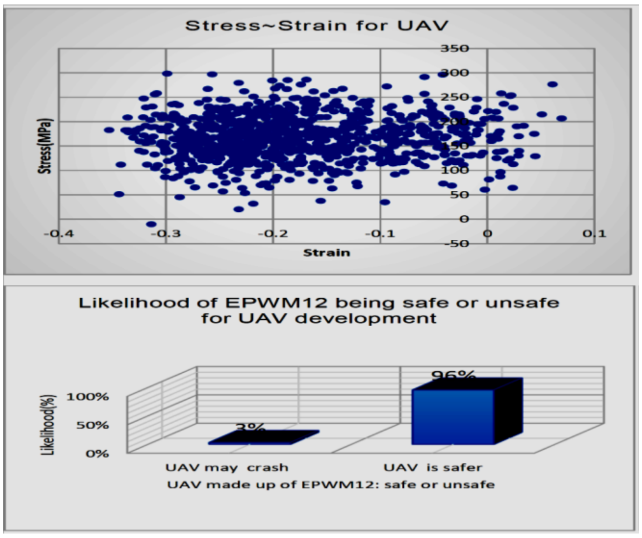


Fig.22 Monte Carlo Simulation of EPWM12

IV. CONCLUSION

In this experimental study an attempt has been made to develop polymer matrix composite laminate 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 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 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 graphene 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 value of %vol. of GO addition to Epoxy resin has not much impact on the strength and Young's modulus. For the same impact load, the fuselage has deformed more than the wing by around 60% during the impact test. One of the reasons could be the shape of fuselage and fiber orientation and concentration at a spot on it . The resistance of the wing at a specific location is more because of the nature of fiber orientation and compactness in a smaller area of cross section of wing.The Monte Carlo simulation showed that likelihood of EPWM12 material being safe for UAV is 96%.

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