FABRICATION AND CHARACTERIZATION OF CFRP COMPOSITE LAMINATES WITH INDUCED DISCONTINUITIES

CHAITHRA. B. K¹, C. S. PRASAD², VITALA H. R³ & DILEEP. B. P⁴

^{1,3}Department of Mechanical Engineering, SJB Institute of Technology, Bengaluru, India

²Department of Mechanical Engineering, R.V. College of Engineering, Bengaluru, India

⁴Department of Mechanical Engineering, Amrita School of Engineering,
Amrita Vishwa Vidyapeetham University, Bengaluru India

ABSTRACT

A composite material, which exhibits comparably high specific stiffness and very low coefficient of thermal expansion (CTE), furnish the necessary characteristics to fabricate lightweight and highly dimensionally stable components. Among this laminated composites made up of carbon fiber reinforced plastics (CFRP) is the most promising candidate and in use for space structure building. This project aims to study the possible discontinuities in the laminates resulting due to the extension of fibers and their influence on the behavior of the CFRP. The standard pattern of discontinuities are induced initially in the laminates prepared using CFRP prepare and their influence on the strength is quantified experimentally for tensile and bending stress. Experimental, and Numerical studies are proposed to quantify the behavior of CFRP with induced continuities and also the direction of laminas also optimized w.r.to the position of load.

KEYWORDS: Carbon Fibre Reinforced Plastics (CFRP), Fibers

Received: Feb 25, 2018; **Accepted:** Mar 19, 2018; **Published:** Mar 31, 2018; **Paper Id.:** IJMPERDAPR2018147

INTRODUCTION

Carbon fibers reinforced plastics (CFRP)[1], proved almost same properties of Boron composites but CFRP is much economical in the market. CFRP is proven by many researchers a modulus[2], of the order of almost three times better than of glass reinforced plastics[3], It is also stronger by three times that of, approximately the same as that of GRP, and slightly less than that of Kevlar composites[4],. Aerospace CFRP does, however, suffer from some disadvantages. It is a brittle material [5], and therefore does not yield plastically in regions of high- stress concentration [6]. Its strength is reduced by impact damage which may not be visible and the epoxy resin matrices can absorb moisture over a long period which reduces its matrix dependent properties[7], such as its compressive strength; this effect increases with the increase of temperature[8]. Resin-impregnated CFRP fiber forms, most commonly known as “prepregs,” are mainly produced by impregnating dry carbon fibers with a well-controlled quantity of resin (thermoset or thermoplastic) [9], using solvents, hot-melt process or by powder impregnation techniques [10]. During the processing of a CFRP laminate part, the ingredient materials of a composite materials react differently to the changes in environmental conditions [11], encountered during processing. Chemically, the reinforcing carbon fibers do not experience significant change during the process cycle; whereas, the thermoset polymer matrix [12], on the other hand, contracts during curing stages. This induces chemically-induced deformations [13], and thermally-induced deformations during processing. Any deviation from

the manufacturing results in degradation of mechanical properties [14]. This is further complicated in the fabrication of large CFRP parts where in order to ensure fiber continuity some kind of joining has to be employed. One way is to introduce overlap of layers which results in a local increase in thickness [15]. When such a method is not acceptable for any reason, deliberate gaps are introduced in the lay-up. These types of discontinuities locally reduce the structural strength [16] of the laminate. Such reduction has to be quantified properly and these data form the basis for the design and analysis of large structural components such as solar panels.

Mechanical Properties of Participant Materials

Table 1: Properties of Prepreg

Properties of CFRP Prepreg	Values
E_T (longitudinal)	283 GPa
E_T (transverse)	7.2 GPa
μ	0.23
G_{LT}	3.87 GPa

Table 2: Epoxy Properties

Properties	Values
E^T	4 GPa
μ	0.42
G	1.4 GPa

EXPERIMENTAL PROCEDURE: PROCEDURE FOR MAKING COUPONS

For Tensile Test with Gap

An 8 pieces of CFRP prepreg of dimension 450x300 mm were cut. A Steel plate of dimension 450x300 mm was prepared and the first layer of prepreg was applied to the steel plate. Subsequently 2nd, 3rd layers were applied. The 4th, 5th layers were applied with a gap of 1mm in a gauge length of 250mm as shown in

Figure 1: The 6th, 7th, 8th Layers Were Applied By Hand Lay-Up Subsequently. Position of Gap is Accurately Marked On The Laminate.

For Flexure Test with Gap

16 pieces of CFRP prepreg of dimension 450x200 were cut. A Steel plate of dimension 450x200 mm was prepared and all the 16 layers were applied to a steel plate by hand lay-up. Only 3rd, 4th, 13th and 14th layers were applied

with a gap of 1mm in a gauge length of 250mm as shown in Figure 2. The position of a gap was accurately marked on the laminate.

Procedure for Making Flexure Coupons with Overlap

12 pieces of CFRP prepreg of dimension 450x200, 4 pieces of 450x160 mm, and 4 pieces of 450x60 mm were cut. The first layer of dimension 450x60 was applied to the steel plate. The next layer of dimension 450x160 was applied in such a way that there is an overlap of 20mm as shown in Figure 3. In top most and lower most 2 layers, the overlap of 20mm was given. All other 12 layers of dimension 450x200 were applied by hand-lay upped subsequently

Figure 3

After the preparation of specimen, vacuum Bagging is done and kept in an autoclave for standard temperature cycle shown in the figure.

The laminates were cut according to ASTM standard test specimen for tensile and three- point bending tests.

Strain gauges were bonded to the surface of top or bottom of the coupon to get longitudinal and transverse strains. UTM is used for tensile loading and 3 points flexure loading of coupons.

Analysis Specimen Preparation

Finite element analyses were done by NASTRAN. The major idea was to build a virtual model which closely represents the possible discontinuities and overlaps in CFRP laminates and predict ultimate loads and strength degradation reasonably. Furthermore, experimental results obtained from tensile test and three support bending tests were conducted to make sure the applicability of the FE analysis technique. The methodology followed in this work can be explained under following steps:

As per ASTM standard the 2D tensile specimen, Flexure specimen was created by using QUAD 4 element.

After meshing the specimens the load and boundary conditions are applied as per respective ASTM standards. Strength degradation and failure loads in the specimen are analyzed by gradually increasing the loads and observing for failure. Respective material properties are applied.

For continuous tensile and flexure specimens, the layup sequence has been assigned by CFRP prepreg properties as shown in the figure. For discontinuous tensile and flexure specimens, the gap region in the FE model was filled with epoxy resin properties as per assumption and the continuous region was assigned CFRP prepreg properties. For discontinuous tensile specimen gap was introduced in 4th and 5th layers. For discontinuous flexure specimens, the gap was introduced in 3rd, 4th, 13th, and 14th layers. After applying lamina, orientation, the tensile and flexure specimen applied for **linear static analysis**. it is a structural finite element solution that allows for temperature dependent elastic material properties. Here the analysis was carried out on CFRP laminates to obtain stresses and strains on each layer of the laminate.

RESULTS AND DISCUSSIONS

As per 2. 1, 2. 2, 2. 3, six types of test coupons according to ASTM standards by introducing discontinuities were produced and tested. The failure loads, strength properties, and material properties have been averaged for 6 types of specimen and shown in Table 1. Comparison of test data with analysis results shows close match. Therefore, it can be said that the methodology followed in their project can be used to generate design data for production of large CFRP parts with fiber extension. Results are grouped under 3 headings:

- Experimental results
- Analytical results
- Comparison of the two results.

Experimental Results

Six types of specimens designated as G_1 , G_2 , G_3 , G_4 , G_5 , and G_6 were tested. In each case, a batch of 10 specimens was tested. For flexure three points bending is devised as per ASTM standard. Failure loads, Young's modulus, ultimate stress and ultimate strain, as well as coupon width and thickness, have been averaged for a batch of coupons. Average experimental results for six types of batches are as follows:

Table 3: Average Experimental Results

Sl.No	Type of Specimen	Failure Load (N)	Width (mm)	Thickness (mm)	Young's Modulus (GPa)	Ultimate Stress (MPa)	Ultimate Strain (%)
1	Continuous tensile(G_1)	10437.8	12.8	0.51	331.8	1569.6	0.5
2	Discontinues tensile(G_2)	9329.3	13.4	0.49	277.2	1402.83	0.57
3	Continuous flexure(G_3)	313.9	24.5	1	309.3	1177.2	0.38
4	Discontinues flexure(G_4)	255.1	24.6	0.96	290.9	1000.62	0.36
5	Continuous flexure(G_5)	264.9	24.4	0.94	301.3	1108.53	0.37
6	Overlap Discontinues flexure(G_6)	372.8	24.6	1.12	319.2	1079.1	0.34

Results from FE Analysis

A result from NASTRAN analysis assumes the dimensions of standard ASTM coupons. Required thickness is achieved by adding a number of layers. Material properties, strength properties, and appropriate boundary conditions are applied to the model and each type of coupon is analyzed. The induced stress is analyzed for the tensile load in steps of 490.5N from 6867N to 11772N progressively. Similarly, for the three- point bending analysis, flexure failure load is applied in steps of 19.62N from 333.54N to 706.32N progressively.

When there is a gap in a layer, the properties of the epoxy that fills the gap will be taken for analysis of stress locally. The specimens are also subjected to analysis for Tsai-Hill failure theory. When Tsai-Hill number is more than 1 it means failure for that particular load. In every case, the failure load, failure stress, Tsai-Hill numbers are shown in Table 4

to 9.

Table 4: Tensile Continuous Specimen

Load (N)	Stress (MPa)	Displacement (mm)	Strain (%)	Tsai-Hill Number
11526.75	1574	0.95	0.41	1.01

Table 5: Tensile Discontinuons Spécimen(Gap)

Load (N)	Stress(MPa)	Displacement (mm)	Strain (%)	Tsai-Hill Number
10202.4	1560 (1 st layer)	1.03	0.45	1.01 (1 st layer)
	1383.2 (4 th layer)	1.03	0.45	0.80 (4 th layer)

Table 6: Flexure Continuous specimen

Load (N)	Stress (MPa)	Displacement (mm)	Strain (%)	Tsai-Hill Number
451.26	1120	1.95	0.33	1.01

Table 7: Flexure Discontinuous Specimen (Gap)

Load (N)	Stress (MPa)	Displacement (mm)	Strain (%)	Tsai-hill number
382.59	1190(1layer)	1.77	0.29	1.01(16 layer)

Table 8: Flexure Continuous Specimen (Without Overlap)

Load (N)	Stress (MPa)	Displacement (mm)	Strain(%)	Tsai-hill number
431.64	1080	1.89	0.32	1.01

Table 9: Flexure Discontinuous Specimen (Overlap)

Load(N)	Stress(MPa)	Displacement (mm)	Strain(%)	Tsai-hill number
676.89	1040	1.65	0.29	1.01

Comparison of Experimental Results with NASTRAN Results

In each case, the results from tests are compared with NASTRAN results. The comparison of failure load in each case is tabulated in Table 10 and the comparison of stress, strain in each case is tabulated in Table 11.

Table 10: Comparison of Test and NASTRAN Results for Failure Load

Type of Specimen	Failure Load From Test (N)	Failure Load From NASTRAN(N)
Tensile continuous	11960.35	11526.75
Tensile Discontinuous	10544.09	10202.4
Flexure continuous	470.88	451.26
Flexure Discontinuous	402.21	382.59
Flexure(without overlap) continuous	451.26	431.64

Flexure Overlap discontinuous	676.89	647.46
-------------------------------	--------	--------

Table 11: Comparison of Test and NASTRAN Results for Stress and Strain

Type of Specimen	Failure Stress from Test (MPa)	Failure Test from NASTRAN(MPa)	Failure Strain from Test (%)	Failure Strain from Nastran (%)
Tensile continuous	1569.6	1574	0.5	0.41
Tensile Discontinuous	1402.8	1560	0.57	0.45
Flexure continuous	1177.2	1120	0.38	0.33
Flexure Discontinuous	1000.6	1190	0.36	0.29
Flexure continuous	1108.5	1080	0.37	0.32
Flexure Overlap discontinuous	1079.1	1040	0.34	0.29

CONCLUSIONS

A method has been developed to characterize CFRP laminates with induced discontinuities, which represent gap or overlap in fibers required to extend the fibers, to produce large components.

The characterization of such CFRP laminates has been accomplished as follows:

- By modeling and analyzing the stresses and strains through finite element methods.
- By fabricating standard tensile and flexure test coupons according to ASTM standards and subjecting them to load tests.
- Comparing the FEM results with test data to understand the efficacy of predicting the failure modes by analytical means.

Comparison of analysis data with test results shows that fiber extension in CFRP component either by overlap or gap can be satisfactorily analyzed using Nastran FEM package, in particular following conclusions can be made.

- The strength variation or reduction of CFRP laminates due to gap or overlap can be satisfactorily modeled and analyzed using FEM packages.
- The test results closely match with the analysis results for the batch of CFRP material tested.
- The methodology has been developed to generate design data for large CFRP parts that might need an extension of fibers.
- This work also provides inputs to carry out repair work on damaged CFRP parts through the introduction of fibers by overlap.

REFERENCES

1. P. Berbinau, C. Soutis, I. A. Guz, "Compressive failure of 0° unidirectional carbon-fibre-reinforced plastic (CFRP) laminates by fibre micro buckling", *Composite science and technology*, vol.59 (1999), pp 1451-1455.
2. S. M. Spearing & P. W. R. Beaumont, "Fatigue damage mechanics of composite materials (I): Experimental measurement of damage and post-fatigue properties", *Composites science and technology*, vol. 44 (1992), pp 159-168.

3. B. Pradhan, N. Venu Kumar, N. S. Rao, "Stiffness degradation resulting from 90° ply cracking in angle-ply composite laminates", *Composites science and technology*, vol.59 (1999), pp 1543-1552.
4. Janis Varna, "Physical interpretation of parameters in synergic continuum damage mechanics model for laminates", *Composite science and technology*, vol.68 (2008), pp 2592-2600.
5. Shuxin Li, Cangtu Jiang & Songlin Han, "Modeling of the characteristics of fibre reinforced composite materials damaged by matrix-cracking", *Composite science and technology*, vol.43 (1992), pp 185-195.
6. J. L. Rebiere & D. Gamby, "Analytical and numerical analyses of transverse cracking in a cross-ply laminate- influence of the constraining effect", *Composite structures*, vol.20 (1992), pp 91-101.
7. Wei Cheng Cui & Michael R. Wisnom, "Contact finite element analysis of three-point and four-point short-beam bending of unidirectional composites", *Composites science and technology*, vol.45 (1993), pp 323-334.
8. V. Ravi Kumar, B. P. Dileep, S. Mohan Kumar, and M. V. Phanibhushana, *Effect of metal coatings on mechanical properties of alluminium alloy*, *AIP Conference Proceedings* 1859 (2017), 020037-1 – 020037-6.
9. Hasan Yildiz, Mehmet Sarikanat, "Finite element analysis of thick composite beams and plates", *Composite science and technology*, vol.61 (2001), pp 1723-1727.
10. D. T. G. Katerelos, M. Kashtalyan, C. Soutis, C. Galiotis, "Matrix cracking in polymeric composites laminates: Modelling and experiments", *Composite science and technology*, vol.68 (2008), pp 2310-2317.
11. O. Allix, E. Vittecoq, "Modelling and identification of the mechanical behaviour of composite laminates in compression", *Composites science and technology*, vol.51(1994), pp 35-42.
12. Dileep B P, B.R, Sridhar, "A Investigation on Mechanical and Metallurgical Properties of Steel EN24 and SiC MMCs, *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, Vol. 8, Issue 2, Apr 2018, 189-194
13. Masoud Motavalli, Peter Flieler, "Characterization of unidirectional carbon fibre reinforced plastic laminates", *Materials and structures*, vol.31 (April1998), pp 178-180.
14. Loretta Dyson, Ethel Garcia, Christina Randopoulos, "Tensile Testing of Carbon Fibre Reinforced Plastic (CFRP) Laminate Strips".
15. Dileep, B. P., RaviKumar, V. Prashanth Mrudula, and M. V. Phanibhushana, "Effect of zinc coating on mechanical properties of Al 7075", in *Applied Mechanics and Materials*, 592-594, 2014 pp, 255-259
16. Reddy JN, *Introduction to finite element method*, 2nd ed, New York: McGraw Hill, 1993.
17. V. Ravi Kumar, B. P. Dileep, and H. R. Vital; *Tribological and mechanical characterization of Al-Ni-SiC metal matrix composites*, *AIP Conference Proceedings* 1859 (2017), 020020.
18. Dileep BP, B R Sridhar; *A Investigation on Mechanical and Metallurgical Properties of Steel EN24 and SiC MMCs, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN(P): 2249-6890; ISSN(E): 2249-8001 Vol. 8, Issue 2, Apr 2018, 189-194*