An Investigation into Carbon/Epoxy Composites for Conceptual Design of Automobile Vehicle Under Various Loads

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Abstract

In this study the finite element analysis of CFRP square beam, which is used for chassis have been studied using bending and torsion loading cases. Total 8 sequences have been studied using ANSYS software. According to the Tsai–Wu failure theory and the results of reserve factor (strength to stress ratios) the fiber direction and stacking sequence design for square section beam have been discussed. Based on the finite element analysis it is observed that the stacking sequences [0/90/45/-45]s , [-45/45/0/90]s and [90/0/0/90]s are the better for the composite structural members of a vehicle.

Keywords. Carbon fiber reinforced polymer, stacking sequence, finite element analysis, automotive, lightweight Design.

1. INTRODUCTION

Composite material consists of fibre and matrix materials which are used in automotive industries because of its high strength to weight ratio, high impact strength, and low density and flexible in the design. Understanding the structural behaviour of composite materials with the complicated geometrical profiles under various loading situations is a challenging task. Different FEA software like ANSYS, ABAQUS, NASTRAN etc predicts the behaviour of the structure efficiently in terms of stresses and deformations. Finite element analysis is very challenging when designing an anisotropic material like carbon-glass fibre reinforced members which is used for a vehicle [1-6.

Many researchers have made attempts to understand the structural behaviour of composites, using FEA software and to replace the existing metallic automotive components with Fiber Reinforced Plastic (FRP) composites [1-10]. Finite element analysis predicted well the stress distribution and failure stress of the critical regions observed during experimental tests. Composite monocoque chassis analysed using finite element analysis on the geometry and laminate lay-ups of a chassis [1]. Optimal stacking sequence determined according to the maximum stress theory and the results of strength to stress ratios [2]. Finite element analysis of simplified part samples have been carried out under various loads. By calibrating the test sample at the coupon and element level, it is possible to predict the structural response at a higher structural level [3]. The damage behaviour of an aluminium–composite hybrid beam under three point bending loading was investigated by a finite element analysis [4]. Different various designs of glass carbon thermoplastic (GCMT) were discussed using FEA [5]. Stacking sequence of the automotive composite lower arm using carbon-epoxy was optimized using micro-genetic algorithm [8]. Development of CFRP lightweight structure for electric vehicles carried out. The multi-scale analysis approach proposed is generic and can be used for other lightweight vehicle structure made of composites [9]. The effect of stacking sequence and fiber orientation angle on the performance of drive shaft was investigated numerically [10].

Objective of this present study is the FEA of hollow beam with different stacking sequence, under the bending and torsional loads. In this paper ANSYS composite pre-post tool is used for composite analysis. Reserve Factor (RF) has been determined based on Tsai-Wu failure criteria for all eight different stacking sequences.

2. MATERIALS AND DESIGN

In this study unidirectional carbon-epoxy composite material has been used. Material properties of these composite is given in Table 1. Carbon-epoxy composite material consists of two parts: a matrix and reinforcement. In carbon-epoxy composite material the reinforcement is carbon fiber, which provides its strength. The matrix is epoxy a polymer resin, which binds the reinforcements together. Carbon-epoxy composite material consists of two distinct elements, the material properties depend on these two elements. Figure 1 shows the material co-ordinates system.

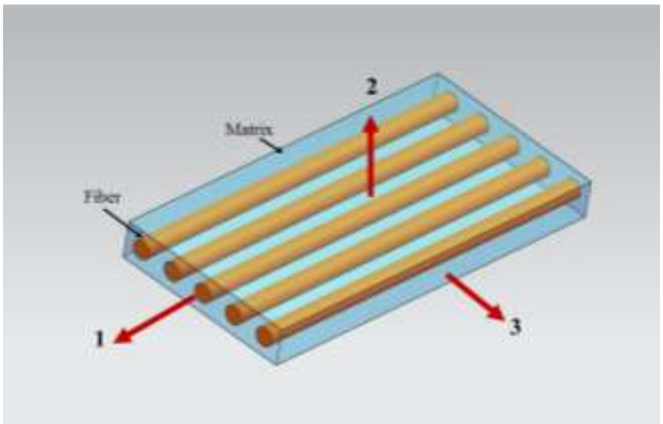

Figure 1. Material coordinate system for hollow square beam (1, 2, 3)

Four different fiber directions have been selected based on reference, which are 0º, +45º, -45º, and 90º [2]. Total 8 layers of each thickness 0.64 mm with total thickness 5.12mm are used for FEA.

Table. 1. Material properties of carbon-epoxy composite [11]

Property	Value	Unit
E1	1.21x105	Mpa
E2	8600	Mpa

E3	8600	Mpa
Density	1.49x10-6	Kg/mm3
G12	4700	Mpa
G23	3100	Mpa
G13	4700	Mpa
µ12	0.27	
µ23	0.4	
µ13	0.27	

Axis of the beam (X axis of structure coordinate system) is taken as a reference direction for stacking up as shown in Figure 2. Total 8 different stacking sequences considered in FEA are given in Table 2.

Table 2. Stacking sequence

Sample	Stacking sequence
1	[00/00/00/00]s
2	[00/90/45/-45]s
3	[-45/45/90/00]s
4	[-45/45/00/90]s
5	[00/90/90/00]s
6	[90/00/00/90]s
7	[90/90/90/90]s
8	[45/45/45/45]s

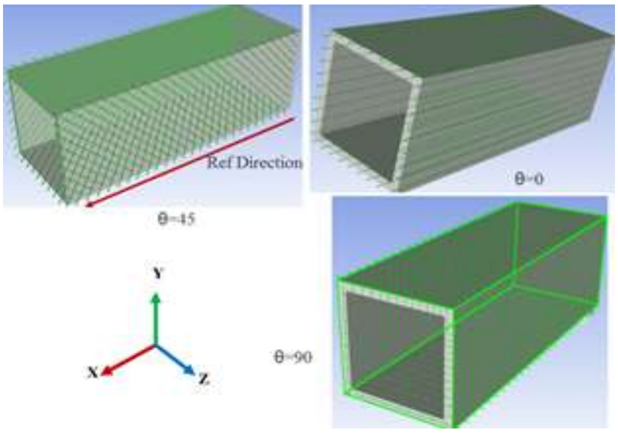

Figure 2. Structure Coordinate system (X, Y, Z)

3. FAILURE CRITERIA

In this study, the Tsai-Wu failure theory is used [9]. This criterion implies the quadratic equation to express a failure envelope surface, which attempts to fit experimental values. It accounts for the stress interaction but does not predict the specific failure mode.

$$f = \frac{\sigma_1^2}{X_t X_c} + \frac{\sigma_2^2}{Y_t Y_c} + \frac{\sigma_3^2}{Z_t Z_c} + \frac{\tau_{12}^2}{S_{xy}^2} + \frac{\tau_{13}^2}{S_{xz}^2} + \frac{\tau_{23}^2}{S_{yz}^2} - 0.5\frac{\sigma_1\sigma_2}{\sqrt{X_t X_c Y_t Y_c}} - 0.5\frac{\sigma_2\sigma_3}{\sqrt{Y_t Y_c Z_t Z_c}} - 0.5\frac{\sigma_1\sigma_3}{\sqrt{X_t X_c Z_t Z_c}} + \sigma_1\left(\frac{1}{X_t} - \frac{1}{X_c}\right) + \sigma_2\left(\frac{1}{Y_t} - \frac{1}{Y_c}\right) + \sigma_3\left(\frac{1}{Z_t} - \frac{1}{Z_c}\right)$$

Reserve Factor = Ultimate Strength/Ultimate Load

Failure RF ≤1

Safe RF ≥1

4. FINITE ELEMENT MODEL

A square hollow beam is selected for the analysis. The meshing of the beam is shown in Figure 3- 4 with total number of 936 SHELL elements and 972 Nodes. For determining the performance of the beam under bending, 3 point bend virtual test is carried out by applying a central static load of 40 KN, which leads to a maximum bending moment of 1700 Nm as shown in Figure 3. For determining the performance of the beam under torsional loading, a twisting moment of 1.7KN-m is applied at the one end, while the other end is fixed as shown in Figure 4.

For bending as well as for torsional loading (other parameters constant) the stacking sequence has been changed. The Reserve Factor (RF) is calculated as per Tsai-Wu failure theory, the maximum deflection is also determined for each sample.

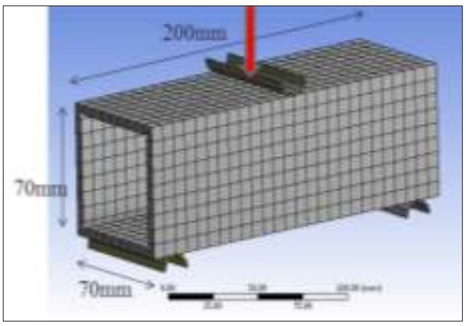

Figure 3. 3 point bend test

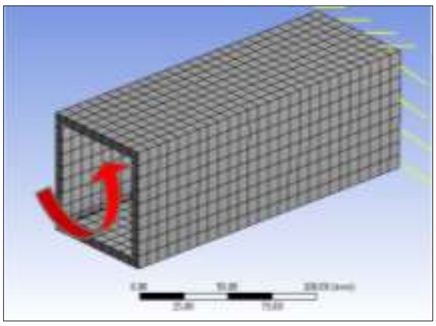

Figure 4. Torsion test

5. RESULT AND DISCUSSION

Results of deflection of the beam with [0/0/0/0] stacking sequence in bending is shown in Figure 5 and deformation with [90/0/0/90] stacking sequence in twisting respectively is shown in Figure 6. Table 3 and 4 list all values of RF, deflection and angle of twist for 8 samples under the bending and torsional loading.

Table 3. Point Bend Test Results

Sample	Stacking sequence	Reserve factor bending	Max Deflection (mm)
6	[90/00/00/90]s	0.693	0.795
2	[00/90/45/-45]s	0.651	0.470
5	[00/90/90/00]s	0.544	0.798
4	[-45/45/00/90]s	0.524	0.486
3	[-45/45/90/00]s	0.467	0.488
7	[90/90/90/90]s	0.417	1.172
8	[45/45/45/45]s	0.346	1.041
1	[00/00/00/00]s	0.230	1.170

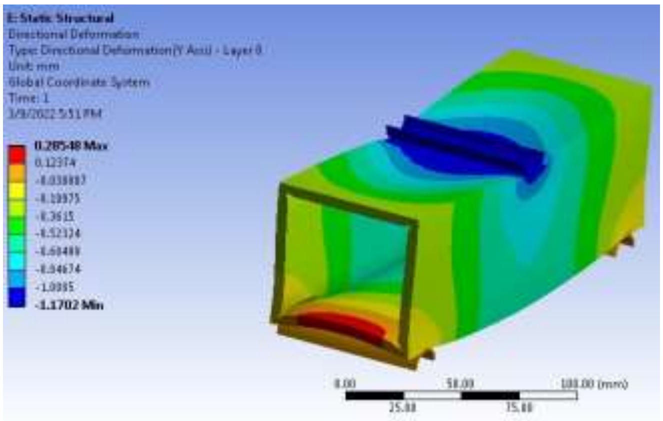

Figure 5. Deflection of the beam for [00/00/00/00] stacking sequence in Bending.

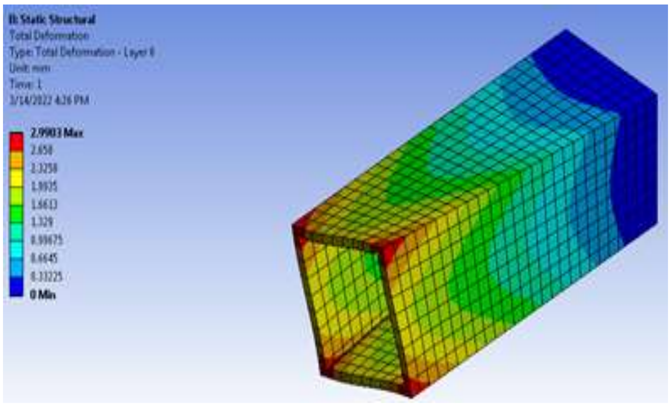

Figure 6. Deformation of the beam for [90/00/00/90] stacking sequence in twisting

Table 4. Torsion test results

Sample	Stacking sequence	Reserve factor torsion	Angle of twist (Deg)
4	[-45/45/00/90]s	0.5988	1.00
8	[45/45/45/45]s	0.5827	1.02
6	[90/00/00/90]s	0.5467	1.72
2	[0/90/45/-45]s	0.5424	1.11
7	[90/90/90/90]s	0.4433	1.75
3	[-45/45/90/00]s	0.4274	0.99
5	[00/90/90/00]s	0.4236	3.41
1	[00/00/00/00]s	0.2827	3.44

The structural members of a vehicle can be subjected to various loads, the best stacking sequence for both the test can be predicted based on above results. In bending [90/00/00/90]s stacking sequence has the highest value of RF which is 0.6934, whereas [00/00/00/00]s stacking sequence has the lowest value of RF 0.2302. In torsion [-45/45/00/90]s stacking sequence has the highest value of RF which is 0.5988 whereas [00/00/00/00]s stacking sequence has the lowest value of RF which is 0.2827. Hence stacking sequences [0/90/45/-45]s, [-45/45/00/90]s and [90/00/00/90]s are the better designs in bending as well as torsion. It is also observed that the unidirectional laminates, i.e. [00/00/00/00]s, [90/90/90/90]s, and [45/45/45/45]s, are the poor designs.

Under three point bending, the deflection of [00/90/45/-45]s stacking sequence is lowest, where as[90/00/00/90]s stacking sequence is at highest. In torsion [-45/45/90/00]s stacking sequence is having minimum angle of twist, while [00/00/00/00]s stacking sequence is having maximum angle twist. Considering all three parameters i.e. RF, deflection and angle of twist in all eight cases the [-45/45/00/90]s is the optimum stacking sequence.

6. CONCLUSION

In this study the finite element analysis of square beam have been carried out with bending and torsional loading. The finite element analysis results comparison showed that the stacking sequences [00/90/45/-45]s, [-45/45/00/90]s and [90/00/0/90]s are the better designs for the composite structural members of a vehicle. Unidirectional laminates, i.e. [00/00/00/00]s, [90/90/90/90]s, and [45/45/45/45]s, are the poor designs which are not recommended for designing. Finally it is concluded that [-45/45/00/90]s is the optimum stacking sequence for bending and torsional loads.

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