

# Analysis of Thin Walled Open Section Composite Beams

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**ABSTRACT:** Composite materials are materials made from two or more constituent materials with significantly different physical property, that when combined, produce a material with characteristics different from the individual components. They are widely used in aviation industry for making different aircraft components. Composites are being used widely as construction material in engineering industries because of their high strength to weight ratio, increased fatigue life and improved damage tolerant nature. In the present study a parametric analysis will be carried out to analyse the effect of fibre orientation, laminate stacking sequence and thickness of layers on the composite beams of C, Hat and Z- cross sections. The characteristics of composites can be exploited to improve the efficiency through proper finite element modeling.

**KEYWORDS:** Composites, Fibre orientation, Finite element model, Thickness, Stacking sequence.

## I. INTRODUCTION

Composites are materials which are made from two or more constituent materials with significantly different physical properties, which when combined will produce a material having characteristics different from the individual constituents. The individual components will remain separate and distinct within the finished structure. The composites are superior to those of the constituent materials acting individually. The composite materials are preferable over isotropic materials due to its properties such as high specific stiffness, high specific strength, low density, resistance to corrosion, easier fabrication, low thermal expansion etc.

Composites are nowadays widely used in aviation industries for making different components of aircraft. In the past, composite materials were used only in manufacturing of secondary structures of aircrafts, but nowadays, due to further advancement in technologies, composites are even used for the manufacture of primary structure. Composite materials are also used in automobile, civil as well as sports industries. Most of the composite structures are designed as assemblies of beams, columns, plates and shells. Thin walled beams of isotropic, orthotropic and composite nature are widely used as stiffeners, stringers and as primary load carrying members in aviation industry. The commonly used stiffener cross sections are Channel section, I section, Hat section, Z section, T section etc.

Materials are used based on the specific application and purposes it has to satisfy. A reinforced concrete beam with steel reinforcement at the bottom is used to carry bending loads which will induce compressive stresses in concrete and tensile stresses in the steel reinforcement. This is an example of a composite material which is designed for a specific purpose. Consider a bundle of glass fibres or carbon filaments, which is useless when used as an Engineering structure. It has no shape and no defined hard surface for machining purposes. Though the bundle can resist tensile forces, it is unable to resist compressive, bending and torsional forces. But, when the bundle of fibres or filaments is dipped into a bath of resin, drained and allowed to harden, it behaves as a new material possessing properties that are comparable to those of steel or other metals, and can also resist forces in tension, compression as well as bending. It has a definite shape, durable surface and can be machined. Such a material is termed as a composite material.

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Composites are produced when two or more materials are combined to attain specific properties that cannot be achieved in the individual components. Composites can be placed into three categories such as particulate, fibre and laminar based on the shapes of the constituent materials. Concrete, which is a mixture of cement and gravel is an example for a particulate composite. Fibreglass, containing glass fibres embedded in a polymer is a fibre reinforced composite and plywood, having alternate layers of wood veneer, is a laminar composite. Advanced systems of fibre reinforced polymers incorporate aramid, glass and carbon fibre in an epoxy resin matrix. Other Engineered laminated composites, such as mallite, use a central core of end grain balsa wood which are bonded to surface of light alloy to generate low weight and high rigidity materials.

Fibre-reinforced composite materials are widely used in products that should be light in weight and strong enough to take harsh loading conditions such as aerospace components (tails, wings, propellers, fuelsages), boat hulls, racing car bodies etc. Other uses include storage tanks, swimming pool panels, fishing rods etc. In spacecrafts industry, the composite carbon is an important material in launch vehicles, heat shields, solar panel substrates, payload adapters, inter-stage structures etc. Disk brake systems of aircrafts and racing cars are using carbon and composite with carbon fibres and silicon carbide matrix is used in sports cars and luxury vehicles. A fiber- reinforced composite pool panel was introduced for in-ground swimming pools, as a corrosion resistant alternative to galvanized steel in 2006. Pipes and fittings for various purposes such as transportation of potable water, irrigation, sewage etc. are nowadays manufactured in glass reinforced plastics.

## II. RELATED WORK

There have been many researches on composite beams in the past, which focuses mainly in analytical studies as well as finite element analysis. Some research works are limited to finding the structural properties like stiffness, centroid, shear centre etc. and finding the individual ply stresses under various loading conditions. Most of the works on composites are limited to symmetrical laminates, specific orientation of fibres, symmetrical geometries etc. Only a few research works were conducted on the torsional analysis of composite beams.

Elghazaly H.A. et. al.[1], (2014) developed an analytical solution for composite laminated beam with Box-section. The solution includes the structural characteristics which are often ignored in the most studies such as axial and bending stiffness. Also, a finite element model has been developed using ANSYS software to validate the results obtained from the analytical solution and it has been seen a good agreement between results. Moreover, a parametric study has been conducted using the developed finite element model. The parametric study includes the effect of fiber orientation angle for symmetric angle ply Box beam on the axial, bending, and torsional deformations. Furthermore, the effect of changing the number of layers in both the web and flange laminates on the axial, bending as well as torsional deformations has been studied.

Pawar P.M. et. al.[2], (2012) carried out static analysis of thin walled composite beam with rectangular cell. The beam was modeled using 3D finite element method for thin walled composite beams. Different ply orientations are selected for each face of the rectangular box beam. The numerical result obtained for thin-walled composite box beams under vertical load was compared with the finite element model to investigate the effect of shear deformation. Thin walled composite box beam is modeled so as weight optimization achieved.

W. S. Chan et al.[3], (2009) focused a simple method based on classical lamination theory & determined the locations of the centroid and the shear center for composite beams with box cross-section. They analyzed aluminum beams with five web angles in both symmetric and unsymmetrical layups. For a symmetrical laminate layup of box beams, the both centroid and shear center locations move toward the bottom flange laminates as web angle is increased. For box beam with 90° web angle (a squared box beam), locations of centroid and shear center are coincided at its geometric center of cross-section. For an unsymmetrical laminate layup of box beam, the centroid location is closer to the bottom flange laminate comparing to the symmetric case. However, the shear center location is further from the bottom flange laminate.

Sanjay Gupta et. al.[4], (2014) done the optimization of composite Z-beam for lowest deflection by a static analysis. Composite materials are extensively being used in aircraft, robotic and automotive industries where the parts are subjected to various loading situations. There is a requirement for the precise prediction of for their static response uniqueness so that they can be designed against the failure because of different types of possible static loads. Here the

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(An ISO 3297: 2007 Certified Organization)

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parameterization of composite is done and then through various parameters like number of ply, ply thickness and ply location etc. the optimization has been done to reduce the weight and other performance criteria's for Z-beam (thin walled composite plate).

Kere et al.[5], (2004) carried out the weight minimization of composite laminates by maximizing the strength for multiple loading conditions with number of layers and layer orientations as design variables. They considered an elastic composite beam with Z cross-section and used FE model to find the stresses. Weight savings are directly associated with a reduced fuel consumption and an increased payload, while the reduced manufacturing cost has an impact on the acquisition cost.

### III. OBJECTIVES, METHODOLOGY AND SCOPE

#### Objectives

- To develop 3D finite element model of composite beam in ANSYS to determine the stresses and strains.
- Optimization of composite beams of C, Hat and Z cross-sections with constraints on the following parameters
  - Laminate stacking sequence
  - Fibre Orientation
  - Thickness of layers

#### Methodology

1. Validation of Finite Element Analysis of Thin Walled Composite Beam section based on study done by Elghazaly H.A. et. al.,(2014). "*Structural Analysis of Composite Laminated Box-Beams under Various Types of Loading*".
2. Finite Element Analysis of Thin Walled Open Section Composite Beams.
3. Optimization of Composite Beams of various cross sections under different laminate stacking sequence, fibre orientation and thickness of layers.
4. Comparison of analysis results.

#### Scope

- Composites are being used widely as construction material in engineering industries because of their high strength to weight ratio, increased fatigue life and improved damage tolerant nature. Thin walled structures are integral parts of an aircraft. They are used in many structures like rotor blades, wing spars antenna legs, submarine hulls, cooling shafts, medical tubing, connecting shafts, transmission poles, carbon fiber tail boom of helicopter and tube like structure in missiles and launch vehicles.
- Several non-classical behaviours are exhibited by thin walled composite structures which include the effect of elastic coupling, transverse shear deformation and restrained tensional warping. These characteristics can be exploited to improve efficiency through proper modeling.
- In this work the optimization of thin walled composite beam will be carried out using 3D finite element model generated in ANSYS.

### IV. FINITE ELEMENT ANALYSIS OF C SECTION COMPOSITE BEAMS

A four layer laminate with orientation  $0^0/0^0/0^0/0^0$  was chosen. Properties of materials chosen are shown in Table I. Three layers of Carbon Epoxy and remaining one layer of Glass Epoxy each having a thickness of 2.5mm were chosen. The cross-sectional dimensions of C-section are shown in Fig. 1. (a). The width of top and bottom flange was assumed as 100mm and the height of web was assumed as 150mm. 10mm thickness was provided for the web as well as flanges of C-section composite beam. After the process of meshing, boundary conditions and loading were provided. One end was provided as fixed while the other end was free. A uniform pressure of 0.1MPa was applied at the top flange as shown in Fig. 1. (b).

Initially, a parametric study was conducted based on the stacking sequence of the section. The fibre orientations as well as the thickness of layers were kept constant. Based on the parametric study conducted on the stacking sequence of

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(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

layers, the optimum section was obtained for the stacking sequence C/C/G/C with a deflection of 4.13243 mm and a stress of 95.0974 N/mm<sup>2</sup>.

The stacking sequence of layers was kept as C/C/G/C and the thickness of all the layers were 2.5 mm. Fibre orientation was altered to get an optimum solution. The optimum section was obtained for stacking sequence C/C/G/C with fibre orientation 0/90/90/0. Beam was analysed after the application of load. The maximum displacement was obtained as 1.99632 mm towards the free end of the beam. Stress generated has a maximum value of 81.5475 N/mm<sup>2</sup> at the bottom flange portion of the fixed end and a minimum value of 0.009872 N/mm<sup>2</sup>. After determining the stacking sequence and fibre orientation for minimum deflection, the thickness of layers were varied and the composite beam section was analysed. The thickness of three graphite layers was kept the same.

A better section was obtained when the thickness of graphite layers was chosen as 3mm and when a thickness of 1mm was provided for the glass layer. In all cases the overall thickness of both the flanges as well as web sections were provided as constant. An overall thickness of 10 mm was provided for the web and flanges of the C-section composite beam. Fig. 1. (c) shows the displacement of the beam when the thickness of graphite layers were 3 mm and the thickness of glass layer was 1 mm. The maximum displacement was obtained as 1.8676 mm towards the free end of the beam.

Material	Glass Epoxy	Carbon Epoxy
E <sub>11</sub>	126.9 GPa	40.3 GPa
E <sub>12</sub>	11GPa	6.21GPa
G <sub>12</sub>	6.6GPa	3.07GPa
μ <sub>12</sub>	0.2	0.2
Density (kg/m <sup>3</sup> )	1610	1910

TABLE I  
MATERIAL PROPERTIES

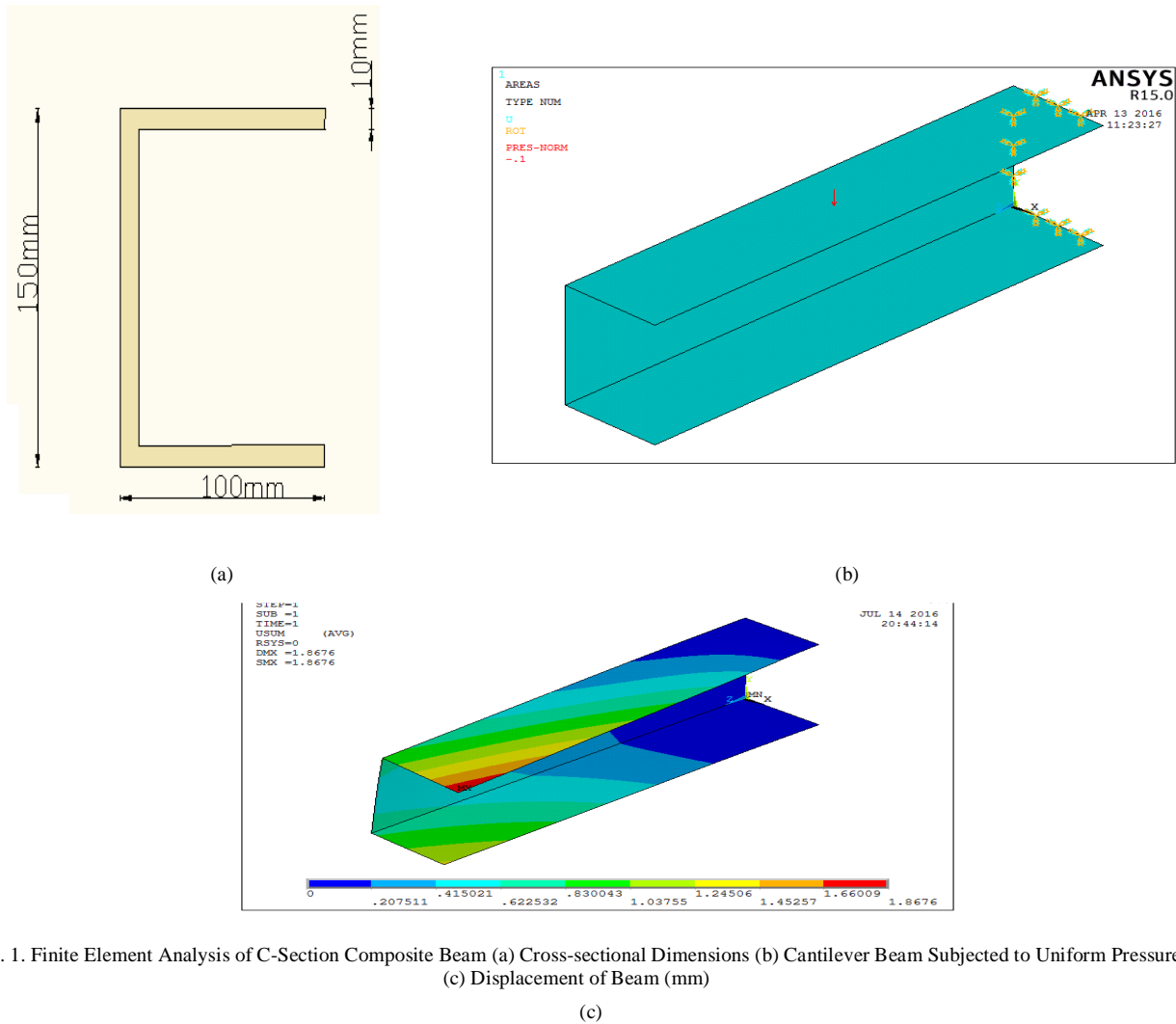


Fig. 1. Finite Element Analysis of C-Section Composite Beam (a) Cross-sectional Dimensions (b) Cantilever Beam Subjected to Uniform Pressure (c) Displacement of Beam (mm)

## V. FINITE ELEMENT ANALYSIS OF HAT SECTION COMPOSITE BEAMS

Finite Element analysis was carried out for a composite beam having hat shaped cross-section having same cross-sectional area as that of the C-section. A four layer laminate with orientation  $0^0/0^0/0^0/0^0$  was chosen. Three layers of Carbon Epoxy and remaining one layer of Glass Epoxy each having a thickness of 2.5mm were chosen. The cross-sectional dimensions of hat section are shown in Fig. 2. (a). A thickness of 10mm was provided for the hat section composite beam. A uniform pressure of 0.1MPa was applied at the top flange. Initially, a parametric study was conducted based on the stacking sequence of the section. The fibre orientations as well as the thickness of all the layers were kept constant. Based on the parametric study conducted on the stacking sequence of layers, the optimum section was obtained for the stacking sequence C/G/C/C with a deflection of 1.12595mm and a stress of 73.0967 N/mm<sup>2</sup>. The stacking sequence of layers was kept as C/G/C/C and the thickness of all the layers were 2.5 mm. Fibre orientation was altered to get an optimum solution. The optimum section was obtained for stacking sequence C/G/C/C with fibre orientation 0/90/90/0. Beam was analysed after the application of load. The maximum displacement was obtained as 0.543483 mm towards the free end of the beam. Stress generated has a maximum value of 72.8326 N/mm<sup>2</sup> at the bottom flange portion of the fixed end.

After determining the stacking sequence and fibre orientation for minimum deflection, the thickness of layers were varied and the composite beam section was analysed. The thickness of three graphite layers was kept the same. A better section was obtained when the thickness of graphite layers was chosen as 3 mm and when a thickness of 1 mm was provided for the glass layer. In all cases the overall thickness of both the flanges as well as web sections were provided as constant. An overall thickness of 10 mm was provided for the web and flanges of the Hat-section composite beam. Fig. 3. (b) shows the displacement of the beam when the thickness of graphite layers were 3 mm and the thickness of glass layer was 1 mm.

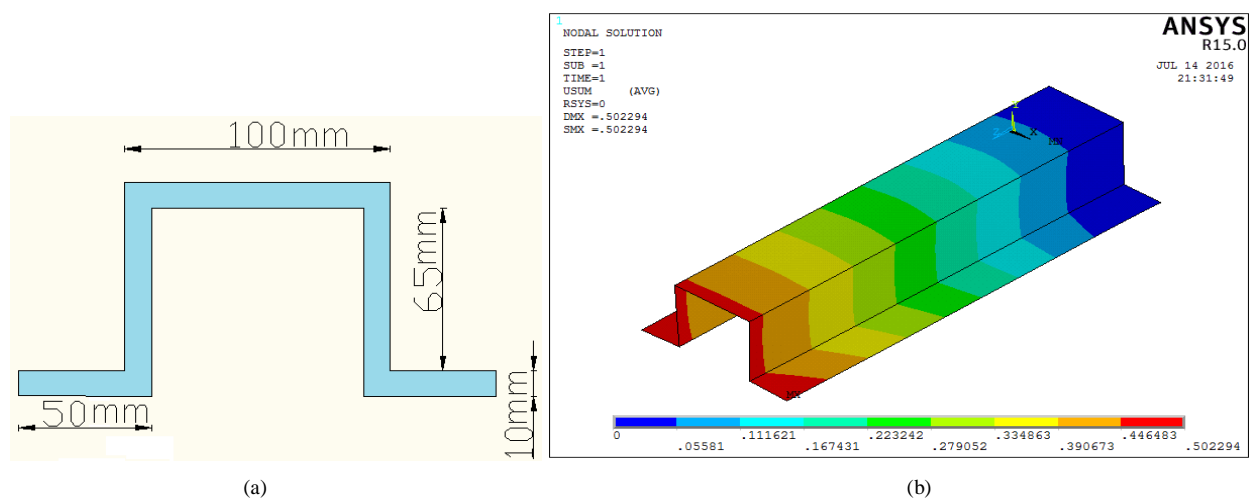


Fig. 2. Finite Element Analysis of Hat-Section Composite Beam (a) Cross-sectional Dimensions (b) Displacement of Beam (mm)

The maximum displacement was obtained as 0.502294 mm towards the free end of the beam. Stress generated has a maximum value of 61.3323 N/mm<sup>2</sup> at the bottom flange portion of the fixed end.

## VI. FINITE ELEMENT ANALYSIS OF Z SECTION COMPOSITE BEAMS

Finite Element analysis was carried out for a composite beam having Z shaped cross-section having same cross-sectional area as that of the C and hat section. The cross-sectional dimensions of hat section are shown in Fig. 3. (a). A thickness of 10mm was provided for the hat section composite beam. After the process of meshing, boundary conditions and loading were provided. One end was provided as fixed while the other end was free. A uniform pressure of 0.1MPa was applied at the top flange to study the behaviour of hat section composite beam. Initially, a parametric study was conducted based on the stacking sequence of the section. The fibre orientations as well as the thickness of all the layers were kept constant. Based on the parametric study conducted on the stacking sequence of layers, the optimum section was obtained for the stacking sequence C/G/C/C with a deflection of 5.475 mm and a stress of 199.356 N/mm<sup>2</sup>.

The stacking sequence of layers was kept as C/G/C/C and the thickness of all the layers were 2.5 mm. The optimum section was obtained for stacking sequence C/G/C/C with fibre orientation 0/90/90/0. Beam was analysed after the application of load. The maximum displacement was obtained as 2.069 mm towards the free end of the beam. Stress generated has a maximum value of 160.896 N/mm<sup>2</sup> at the bottom flange portion of the fixed end.



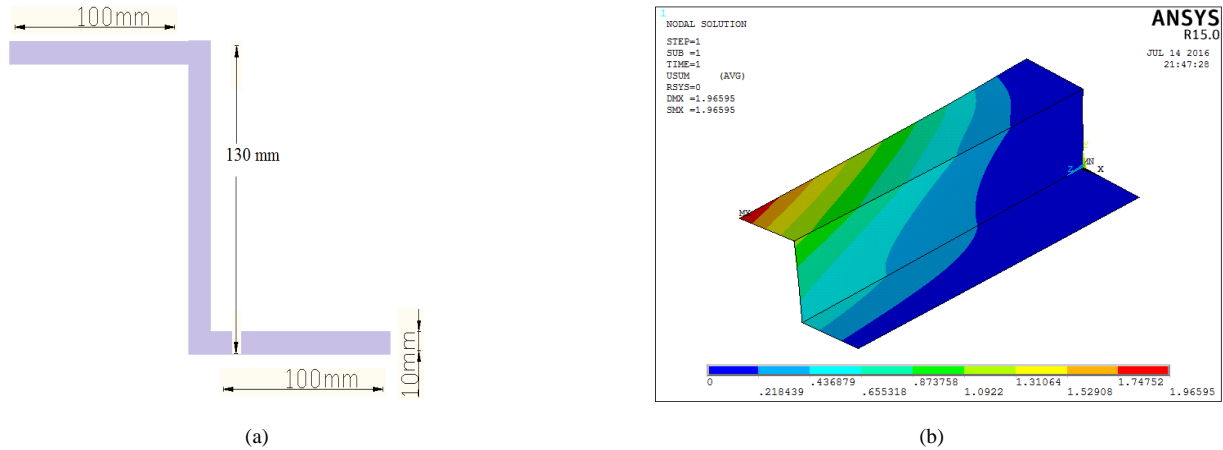


Fig. 3. Finite Element Analysis of Z-Section Composite Beam (a) Cross-sectional Dimensions (b) Displacement of Beam (mm)

Fig. 3. (b) shows the displacement of the beam when the thickness of graphite layers were 3 mm and the thickness of glass layer was 1 mm. The maximum displacement was obtained as 1.96595 mm towards the free end of the beam. Stress generated has a maximum value of  $139.585 \text{ N/mm}^2$  at the bottom flange portion of the fixed end.

## VII. CONCLUSIONS

Composite beams are widely used in the aerospace industry because of their advantages over the commonly used isotropic structures especially when it comes to weight savings. Composite laminates have widespread applications, and optimizations of the corresponding stacking sequences are indispensable. The stresses and strains in plies of sub-laminates of a laminated composite can be calculated with the finite element model. The commercially available finite element software makes it possible to optimize the complicated composite structures.

Optimisation of composite beams of C, Hat and Z sections having same cross sectional area were carried out with constraints on the parameters such as laminate stacking sequence, fibre orientation as well as thickness of layers. For C section optimum section was obtained for the stacking sequence C/C/G/C with a fibre orientation of 0/90/90/0. The deflection obtained was 1.8676 mm and maximum stress was  $74.8643 \text{ N/mm}^2$ . For Hat section optimum section was obtained for the stacking sequence C/G/C/C with a fibre orientation of 0/90/90/0. The deflection obtained was 0.543483 mm and maximum stress was  $72.8326 \text{ N/mm}^2$ . For Z section optimum section was obtained for the stacking sequence C/G/C/C with a fibre orientation of 0/90/90/0. The deflection obtained was 2.069 mm and maximum stress was  $160.896 \text{ N/mm}^2$ .

The characteristics of composites can be exploited to improve efficiency of these materials through proper modelling. The effect of fibre orientation, laminate stacking sequence as well as the thickness of layers can be analysed with the help of Finite Element Model (FEM). In all the cases minimum deflection was obtained for stacking sequence C/G/C/C and for fibre orientation 0/90/90/0. Deflection is obtained as minimum when the thickness of glass layers is kept the least.

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