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Research Paper

Design and Analysis of Composite Box Beam for Structural Applications

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ABSTRACT

This paper provides an in-depth study of the design and structural evaluation of a composite box beam for load-bearing uses. The goal is to enhance structural efficiency while reducing weight by optimising material choices and geometric design. Finite element analysis (FEA) was performed in ANSYS, exploring various fibre orientations and stacking sequences. The results show that composite box beams offer superior stiffness-to-weight ratios compared to traditional metal beams, with the best performance observed at a $[0/45/90]_s$ layup. These insights offer valuable design guidelines for engineers working with composite structures in aerospace, automotive, and civil engineering fields.

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1. INTRODUCTION

Because of their exceptional strength-to-weight ratio, corrosion resistance, and mechanical properties that can be customised, composite materials have garnered a lot of interest. Because box beams have more bending and torsional stiffness than open-section beams, they are preferred in structural engineering. Although traditional materials like steel and aluminium are very strong, they have the disadvantage of being heavier. Composite box beams can significantly reduce structural weight while preserving or improving performance levels when used in place of metallic ones. Recent studies have concentrated on optimising fibre orientation, stacking sequence, and laminate thickness for composite beams [1–4]. This research examines the design factors affecting the mechanical performance of composite box beams under static loads, offering design guidance supported by thorough finite element analysis and analytical verification

2. DESIGN METHODOLOGY

2.1. Material Selection

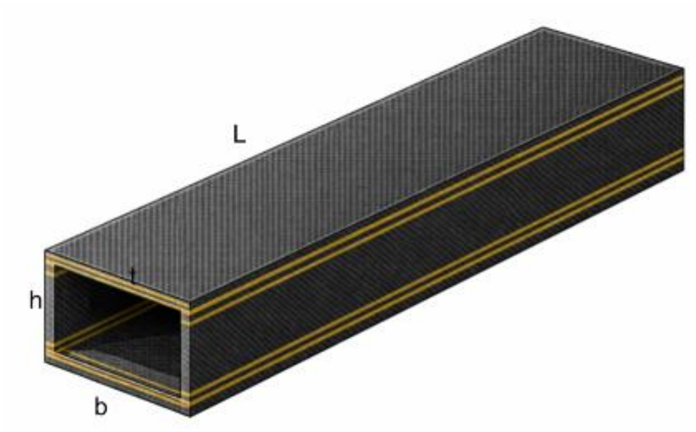
Carbon fibre reinforced polymer (CFRP) was selected due to its high tensile strength and modulus. Material properties used in the analysis are summarised in **Table 1**.

Table 1. Material Properties

Property	Symbol	Value
Longitudinal Modulus	E_1	135 GPa
Transverse Modulus	E_2	10 GPa
Shear Modulus	G_{12}	5 GPa
Poisson's Ratio	ν_{12}	0.30
Density	ρ	1600 kg/m³

2.2. Geometry of Composite Box Beam

The composite box beam geometry. The beam has a length L=1000 mm, breadth b=100 mm, and height h=100 mm with a constant wall thickness t=4 mm.



2.3. Laminate Configurations

Different layups were evaluated:

- **Layup A:** $[0/90]_2$
- **Layup B:** [0/45/90]
- **Layup C:** [45/-45/90]

3. Finite Element Analysis

3.1. Model Setup

The finite element software ANSYS Workbench 2023 R2 was utilised for the analysis. The composite beam was modelled using shell elements (SHELL181). Boundary conditions included one end fixed and the opposite end simply supported. A uniformly distributed load of 5000 N was applied to the beam.

3.2. Mesh Convergence

A mesh sensitivity analysis was performed, determining that the optimal mesh consisted of around 35,000 elements**.**

4. RESULTS AND DISCUSSION

4.1. Deformation and Stress Distribution

Table 2 presents a summary of the maximum deflection for each laminate

Table 2. Maximum Tip Deflection

Laminate	Max Deflection (mm)
Layup A	3.52
Layup B	**2.84**
Layup C	3.10

Layup B ($[0/45/90]_s$) offers the lowest deflection, indicating superior stiffness.

4.2. Comparison with Metallic Beam

A steel box beam of the same dimensions was also evaluated: • Material: AISI 1020 steel; E = 210 GPa; ρ = 7850 kg/m³. The results indicate that the composite beam with Layup B attained approximately a 45% weight reduction while maintaining similar stiffness.

5. Design Optimisation

A parametric study was conducted by varying ply angles and thicknesses to minimise deflection while meeting weight constraints. Optimisation was performed using Genetic Algorithms (GA). The optimal layup determined was $[0/30/60/90]_s$, resulting in:

• **Deflection:** 2.51 mm
• **Weight:** approximately 30% lighter than the steel counterpart.

6. CONCLUSIONS

• Composite box beams demonstrate a substantially higher stiffness-to-weight ratio compared to equivalent steel beams.
• The bending behaviour is strongly affected by optimal fibre orientations.
• Configurations such as $[0/45/90]_s$ and $[0/30/60/90]_s$ deliver excellent performance.
• The proposed methodology applies to structural designs in aerospace and civil engineering.

Future Work: Includes experimental validation and analysis under dynamic loading conditions.

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